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PLEISTOCENE GEOLOGY OF THE UINTA MOUNTAINS

by

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INTRODUCTION.

As its name implies, the purpose of this paper is to discuss the glacial phenomena of the Uinta Mountains. Part I. will be devoted to discriptive material and to an indication of the bearing which certain facts have upon the glacial history of the region. In Part II. general questions will be considered and conclusions drawn from the facts developed in Part I.

It is hardly necessary to state that no living glaciers are found in the region today. The Uintas formed one of the districts of local glaciation in the west which was probably synchronous with the glaciation of the interior.

So far as known to me the only previous work on the glaciation of this district is that which was done by the members of the Survey of the Fortieth Parallel under the direction of Clarance King. No detailed work, however, was done on this problem by them. Their observations simply pointed to the fact that glaciation had occurred on a rather extensive scale, and the glaciated area was indicated on their map by a different color. However, information has been drawn from their work wherever available.

In treating the Pleistocene geology or glaciation of the Uinta Mountains it seems necessary to first give a brief discription of the range.

The Uinta range is an exception to the majority of the Cordilleran ranges both in linear direction and in simplicity of structure. The range proper lies wholly within the state of Utah extending along the east and west jog in the northeastern part of the state which lies under Wyoming. It is the only range of mountains in the west of any importance which does not have a general north and south direction. It lies principally between the parallels of 40° 30′ and 41° N, Latitude, and between the meridians of 108° 30′ and 111° 15′ W. Longitude. This is best shown in Plate I. It is thus seen to be about 150 miles long (east and west) and about 32 miles wide (north and south). Its highest peak is 13,500 feet high, while its average height is about 10,500 feet.

In structure it is characterized by general simplicity, although there are local and minor features that are more intricate and complex. It may be described briefly as consisting of one immense anticlinal fold with a broad flat top, before dissected by erosion, at the margin of which, on either side, the strata have been ruptured with the consequent

production of faults. The major fault line is on the north side of the range and has determined the location of the crest line. On the south the fault is less conspicuous and less easily recognized. The extent of throw and the tilting of the beds are also much less on the south side.

On the top of the arch the strata occupy an almost horizontal position, dipping at most 5 or 6 degrees toward the south. Beyond the break on the southern arm of the uplift the dip increases considerably. On the north arm the angle of dip is much greater than on the south and amounts, in places, almost to verticality. This is well shown in the main Blacks Fork canyon, where, in an excellent exposure is seen the Triassic shales and red beds standing in an almost vertical position, abutting against the older massive quartzites which form the crest of the range.

The different series of rocks represented in that part of the range under consideration are the Uinta series, the Carboniferous, the Triassic and the Jurassic series and the overlying basal conglomerate of the Eocene.

Concerning the age of the Uinta series different opinions have been offered. They overly the Archean rocks, exposed only at Red Creek canyon, unconformably and, according to Major Powell and Prof. Van Hise, are unconformable beneath the Carboniferous limestone.*

*Powell, 'Geology of the Uinta Mountains.' p. 140.
Van Hise, 'Principles of N.A. Pre-Cambrian Geology.' p.820.

These two men also state that no fossils have been found in the formation. Powell suggests that they are of Devonian age but adds that he would yield his opinion on the slightest Palaeontologic evidence. (loc. cit. p. 70) Prof. Van-Hise thinks that they are most probably to be correlated with the belt series of Montana and are therefore Algonkian. (loc. cit. p.821.) King and Emmons, on the other hand, did not recognize the unconformity between the Uinta series and the Carboniferous and claim to have found a very few species of fossils in the quartzite. On these grounds they group the Uinta series of Powell with the Carboniferous and correlate them with the Weber quartzite of the Wasatch Mountains, which name they carry over to this formation in the Uintas. In a foot note, however, King refers to Powell's discovery of an unconformity, published after his own work, and says that if this unconformity exists the Weber quartzite is probably not Carboniferous.*

With the exception of a small patch of Archaean at the east end of the range, the Uinta series is the oldest exposed member and forms the crest of the range, almost without exception throughout its entire length. The series is divided into three subdivisions by King as follows ; (1) a

* Survey of the 40th. Parallel. Vol.II. pp. 199 and 322-323.

lower series of white and reddish, compact, fine grained quartzites; (2) a middle series of purple coarse textured quartzites; (3) an upper series of red and striped sandstone, firmly cemented . The thickness of the formation as given by Powell is 12,500 feet.

Overlying the quartzite unconformably and flanking the range on both sides in parallel ridges, is the upper coal measures, which consists of a basal, dark, fossiliferous limestone overlain by alternating layers of lighter colored limestone and fine grained sandstone. This formation is well exposed in the lower part of the Weber River canyon where the beds have a dip of 30°-45° slightly west and north.

Above this comes the Permo- Carboniferous.

The Triassic and Jurassic formations are well shown on both sides of the range which they flank as somewhat narrow and discontinuous bands.

The only other formation represented within the area at present under consideration is the characteristic Wyoming conglomerate, the basal member of the Eocene, which overlies the Mesozoic unconformably. This is a coarse basal conglomerate containing numerous boulders 2.5 feet in diameter and some with a diameter of 4 feet. It is cemented by a calcareous cement and occurs today as the capping member of some of the hills and plateau like areas on either side of the range. The highest elevation at which it was observed is at

Dead Man's Mountain on the east side of Bear River canyon, elevation 10,800 feet. This conglomerate, where exposed in a good section and in an uncemented condition, has the appearance of a typical bank of till and can be distinguished from the latter only by topographic features and absence of striae. Since the boulders of the drift are not usually heavily striated in this region, an isolated patch of the conglomerate of insufficient dimensions to give topographic characteristics, cannot, with absolute certainty, be dis - tinguished from till.

In closing this brief account of the structure of the range it should be said that the uplift which gave it birth dates from the close of the Cretaceous as shown from the fact that the Cretaceous and all older formations have been involved in the folding, while the post-Cretaceous forma - tions are unaffected. The uplift was of the quiet type un-accompanied by any igneous activity. The rate of uplift must have been slow because the Green River which cuts through the east end of the range, was able to maintain its old channel during the uplift and stands today as a record of the rate of mountain making movement of that time, and also as a type of an antecedent drainage stream.

The remainder of this article will be devoted to a dis-cussion of the glacial phenomena of that portion of the range included in the Hayden Peak quadrangle and part of

the adjoining Coalville sheet. This comprises the western end of the range extending eastward from Kamas Prairie to Black's fork of Green River.

The work on the area was done during a part of the summer of 1902, under the direction of Mr. Atwood of the University of Chicago, from whom many valuable suggestions were received. The accompanying photographs are the work of Mr. A.P. Church.

Each canyon will be discussed individually and in detail, since each was a separate and distinct glacial unit . All unnecessary repetition, however, will be avoided. The main canyon will generally be described first, then the tributaries. We will begin at the west end, work eastward along the north side and then from east to west along the south side. Reference will be made to the accompanying map in describing particular features, and particular points will be located by figures, letters, etc.

PART I.

Swift's Canyon.

This canyon is a tributary to the Weber River canyon but will be described before the main canyon because the two have no connection as far as ice work is concerned, the former being below the lower limit of ice in the latter.

The canyon is on the northwest side of the Uinta range and leaves the Weber about five miles above the town of Oakley, which is situated at the entrance to Weber canyon. The canyon is three and one half miles long and has a direction a little east of south from mouth to head.

In the lower part of the canyon the material consists of alternate layers of sandstone and limestone of Carboniferous age. The limestone contains numerous fossils, principally Zaphrentis corals and brachiopods. The dip of the rock is about 45° so that before half of the canyon is traversed the limestone and sandstone are replaced in the bottom of the canyon by the underlying quartzite which at the head is the only material present.

The lower part of this canyon has not suffered from ice action. About one mile up the canyon a little suggestion of glaciation is encountered and not far above this, drift is found in considerable quantities. The canyon forks at about this point, the main canyon keeping to the right. (When the words right or left are used they always signify to the right or left in going up the canyon.)

The covering of drift is only moderately heavy and belongs mainly to the ground moraine type. Farther up the canyon the drift material becomes more abundant and outlines of the lateral moraines begin to show themselves on the sides of the mountains. The lateral moraines, however, are not so well marked here as in most of the other canyons. Most of the glacial material is found in the bottom of the canyon.

The topography of the drift is that of ground moraine, that is, rolling, with swells and depressions, some large, some small.

The material of the drift varies somewhat from upper to lower limit. In the lower part much limestone occurs and some sandstone, also quartzite. The sandstone and limestone come from the neighboring cliffs and from the talus which had accumulated in the bottom of the canyon, and have not been carried for any considerable distance. Farther up the canyon, as already said, they become a minus quantity. The quartzite may have come from the head of the canyon or have been gathered further down. As a matter of fact it must have come partly from the head and been partly gathered by the ice in its downward movement. So far as physical appearances go there is no way of distinguishing between that derived from the various places mentioned.

Striations were found here, as elsewhere, on the boul -

ders but nowhere was the bed rock shown to be smoothed and polished, as is the case in numerous other instances.

The snow which fed the glacier collected in a rather small basin at the head of the canyon at an elevation of 9000 feet. The lower limit of the ice was about 7,200 feet. This would give a glacier two and one half miles long.

This canyon furnishes rather a good opportunity for contrasting the topography of its glaciated and non-glaciated parts. As already said, about one mile of the lower course of the canyon was not affected by the ice. Neither does this seem to have a great amount of out-wash from the ice. Below the drift the bottom is narrow and decidedly V-shaped with steep walls and perpendicular cliffs. As soon as the drift is encountered in mass the canyon broadens out, the contours are softened, and extreme roughness dies away.

The amount of ice in this canyon was not great for two reasons, (1) the catchment basin is too small, (2) the altitude is not sufficiently high.

South Fork of Weber.

This is another right hand tributary to the main Weber. It leaves the latter from half to three fourths of a mile above Swifts canyon, and heads some seven miles farther back in the range in a general south east direction. The structures and formations represented are essentially like those in Swifts canyon.

Like the latter it was also occupied by ice but not in sufficient amount to extend out into the main canyon.

Smith and Morehouse Canyon.

This is the third and most important right hand tributary of the Weber proper, about seven miles above the mouth of South Fork. It heads about eight miles directly south in the main axis of the range north of Shingle Creek, a tributary of the Provo.

Like the preceding canyons, limestone and sandstone are prominent in its lower course but give way to the quartzite farther up. The canyon is broad and open with a well developed U-form.

A broad terminal moraine from 75 to 100 feet high and one half mile wide extends out beyond the mouth of this canyon into the main Weber canyon. This moraine has the shape of a fan but is broad and flat on top and heavily covered with subangular boulders which give ample evidence of the agent which transported them to their present position. Passing over this terminal and going farther up the canyon, several small recessionals are crossed at short intervals for a distance of one mile. These are not very large but distinct enough to be unmistakable. About one mile below the forks a second large moraine is encountered, which is 20 to 50 feet high, about one fourth mile wide, and extends across the canyon with its convex side down stream. Behind this the canyon is very broad and flat with a low gradient up to the forks. The stream has cut a narrow channel through

the moraine on the east side of the canyon. A project is under way to fill up this gap and do again what nature once did, convert the basin above into a reservoir. Both forks of the canyon contain a light covering of till which shows a decidedly hummocky topography where present in any considerable quantity. The bed rock, wherever exposed, is heavily striated and smoothly planed.

The catchment basin is about three by four miles in extent and nèvè if not ice connected this glacier with that in Shingle and Boulder Creek canyons, on the south side of the range. Several lakes occur in the head of the canyon.

At the forks the ice reached an elevation of 8,500 feet.

This is one of the canyons of the region which has an important bearing on the question of epochs. It has already been noted that the present terminal moraine for Smith and Morehouse canyon extends out into the valley of the Weber in the form of a fan. It is certain that this moraine could not have been built while the Weber was occupied with ice at this point. We also know that at the time of its maximum extension, the ice pushed down the Weber several miles beyond Smith and Morehouse canyon and built lateral moraines on each side of the Weber canyon, traces of which still remain. The terminal from Smith and Morehouse cuts directly across these laterals. An attempt to reproduce the conditions which existed has been made in Figure 1. on the next page.

Figure 1.- Diagram showing the position of a terminal moraine, A.C.D., formed by ice from Smith and Morehouse canyon in the Weber canyon which was itself once occupied by ice below A.C.D. The continuous green lines show the position of the lateral moraines, and the dotted green line, the medial formed by the confluence of the two glaciers.

The continuous green lines represent the lateral moraines in both canyons, the dotted green lines AB, the medial which would have been formed by the confluence of the two glaciers, and the red line A.C,D., the present terminal moraine from Smith and Morehouse. It needs no argument to prove that the moraine A.C.D. could not have been built while the Weber glacier, which in all probability was a much larger and more vigorous one than the Smith and Morehouse glacier, extended down the canyon several miles beyond. Instead of the ice from Smith and Morehouse taking the position A.C.D. it would have been deflected by the Weber ice against the right hand side of the canyon and forced to hug the mountain on that side. It is certain therefore that the moraine A.C.D. was formed by an advance of the Smith and Morehouse glacier into the Weber canyon after the glacier of the latter had retreated up the canyon beyond the point A.

There are two possible ways by which the moraine in question might have been formed; (1) The ice in the Weber may have receded faster than that in the Smith and Morehouse, due to two factors to be discussed later, and therefore, when the ice in the latter was left free from and unobstructed by the ice in the former, it may have still possed sufficient vigor to push out to the position A.C.D. and thus have built the moraine; (2) The ice in both canyons might have receded at an equal rate and the moraine have been formed by a second advance of ice in the Smith and Morehouse.

Taking up the first possibility, that the glacier of the Weber receded faster than the Smith and Morehouse, there are certain factors to be considered which would influence the comparative rates of recession of the two glaciers. The factors are, (1) the size of each névé field, (2) the distance of A.C.D. from each névé field, (3) the gradient of the canyon and therefore the velocity of the ice, in each, between A.C.D. and the respective névé fields, (4) the altitude of the respective névé fields.

The area of the combined névé fields which fed the Weber glacier was something like 16 square miles, the area of the Smith and Morehouse névé field 10 square miles. The ratio is about 1.5 : 1. The Weber canyon therefore gave rise to much the larger glacier. If the comparative size of the glacier was in direct proportion to the névé fields, then Weber glacier was one and one half times as large as Smith and Morehouse. So far as this factor alone is concerned the Weber glacier would have maintained its terminus at A.C.D. longer than the Smith and Morehouse glacier. This factor is therefore inimical to the first possibility.

The ratio of the distances between A.C.D. and each neve field is as $\frac{2}{3} : \frac{1}{2}$ or in terms of unity as $1\frac{1}{4}$: 1[illegible]. So far as this factor alone is concerned Smith and Morehouse glacier could maintain its terminal out at A.C.D. for some time after the Weber glacier had receded beyond

that point. This factor is favorable, therefore, to the first possibility.

The ratio of the gradients per mile, of the two canyons between A.C.D. and the névé field is as 7 : 9 or roughly as 1 : 1⅓ . Because of the greater velocity of the ice due to this greater gradient of canyon, this factor is favorable to the maintainence of the Smith and Morehouse glacier at A.C.D. longer than the Weber glacier.

The altitude of the névé field is on the average about 200 feet higher in Weber than in Smith and Morehouse. This elevation is favorable to the greater accumulation of snow and therefore the production of the larger and more vigorous glacier in the Weber canyon. It is therefore inimical to the first possibility.

Bringing these data together we have the following results ; (1) the gradient of Smith and Morehouse canyon is one third greater per mile between the névé field and the moraine A.C.D. than the average gradient of the Weber between the same points ; (2) the distance between the névé field and A.C.D. is but two thirds as great in case of Smith and Morehouse as in Weber canyon. Both of these factors favor the maintainence of the terminus of the Smith and Morehouse glacier at A.C.D. for a longer period of time than the Weber glacier. On the other hand we have (3) the average elevation of the combined névé fields of

the Weber is 200 feet greater than the Smith and Morehouse névé field, (4) the average size of the combined névé fields of the Weber was one and one half times that of the Smith and Morehouse névé field. This comparison of size is based on measurements of the basins or cirques which lie within the actual drainage of the respective canyons today. During the glacial period we know that the principal névé fields of the Weber were continuous with the much larger névé fields of the North Fork of Provo, Provo proper and Duchense rivers on the south side of the crest. It is therefore probable that the actual névé field from which the Weber glacier received its supply was considerably larger than that given in the estimate. The Smith and Morehouse névé field was, on the contrary, practically isolated and could not have been appreciably larger than the present basin. Hence it seems very probable that the ratio given above is too small and that a ratio of 2 : 1 instead of 1½ : 1 in favor of the Weber would be a more nearly correct one. These two last factors would have favored a greater precipitation and accumulation of snow and a consequent larger and more vigorous glacier in the Weber canyon.

From these more favorable conditions the Weber glacier might have been able to maintain its terminus at A.C.D. longer than the Smith and Morehouse glacier. It therefore

becomes a question as to which of these two sets of factors predominated. It seems highly probable to me that the increased size of the Weber glacier due to the increased collecting area, (2 : 1) and increased elevation (200 ft.) causing greater precipitation, was sufficient to balance if not overbalance the increased gradient, (1½: 1) and shorter distance (1½ : 1) in favor of the Smith and Morehouse glacier. Reasons for this supposition are given more in detail in Part II. under the head of Epochs. If this were the case, then the moraine A.C.D. could not have been built by the Smith and Morehouse glacier at the time of its first retreat. It must, therefore, have been built by a subsequent advance of the glacier and this second advance probably represents a second epoch.

But it may be objected to that the same conditions which controlled the size and maximum extension of the respective glaciers in the first epoch would also predominate in the second and therefore the moraine could not have been built at all, and all of the above arguments appear futile. At first sight this appears to be the case, but when we discuss the Weber canyon with its several tributaries, it will be shown that there is evidence for assuming that during the second epoch, basins 70 and 73 did not collect enough ice to extend out and join the glacier of the main canyon. Therefore the Weber glacier of the second epoch did not possess the advantage over the Smith

and Morehouse of such an increased collecting area and the latter glacier might well have reached A.C.D. while the former fell short of that point.

It is therefore concluded that the moraine A.C.D. represents a second ice advance and probably a second ~~e~~ - epoch, although this readvance might have been one of the first ice sheet after it had only partially receded, in which case we would have but one epoch.

Weber Canyon.

The Weber canyon takes its head in the crest of the range near the west end. It flows north west for eight miles and then makes a broad bend to the westward, which direction it maintains to the town of Oakley, eleven miles beyond. The canyon has a broad open bottom varying from one quarter to one half mile in width. On the right hand side tributaries are given off at intervals throughout its length, of which the most important are, beginning at the mouth,- Swifts canyon, South Fork, Smith and Morehouse, already discussed. At Holiday Park the canyon breaks up into four branches which diverge from this point toward the crest of the range. These forks will be discussed in order from west to east as basins 70, 71, 72, 73.

Basin 70. - This is probably the least characteristic of the four basins. It is three and one half miles long and shows evidence of glaciation principally in its U-shaped form and the presence of lateral moraines which skirt the canyon wall on either side. These are most strongly developed where it merges with its fellows to form the main canyon. The appearance, which is characteristic of tributaries of the larger canyons, is as if the ice from this canyon had been obstructed by the ice from 71 and 72, and had deposited much of its load. Although it has not been proved it may be that this phenomenon is

due to a second advance of the ice sheet in which the smaller tributaries did not produce a glacier sufficiently large to extend out into the main canyon, but merely butted up against the latter.

Basin 71. - This canyon lies between 70 and 72. It is about six miles in length and has a north - south direction. Mt. Watson stands at the head of the basin on the very crest of the range. On either side of Mt. Watson is a low col one of which leads from this canyon into the North Fork of the Provo and the other into the main Provo basin. The canyon has a very broad open bottom, the U-shaped form is almost ideal.

Ice occupied the canyon for its entire length and, uniting with that of the other forks, pushed down the Weber canyon several miles. Two miles above the forks of the stream drift covers the top of the hill between Middle Fork and East Fork, which at the point given is 9,500 feet high or 1,200 feet above the stream. Not only that, but the hill is ~~covered~~ strewn with drift up to 10,700 feet. In the lower part of the canyon a thin covering of drift lies in the bottom, but farther up the loose material is almost entirely wanting and the bed rock is smoothed, polished, and striated most beautifully.

Rôches Moutonnées topography is developed on a larger scale than elsewhere in the region. This development is due to the structure and the nature of the material. The latter is the hard resistant quartzite, characteristic of

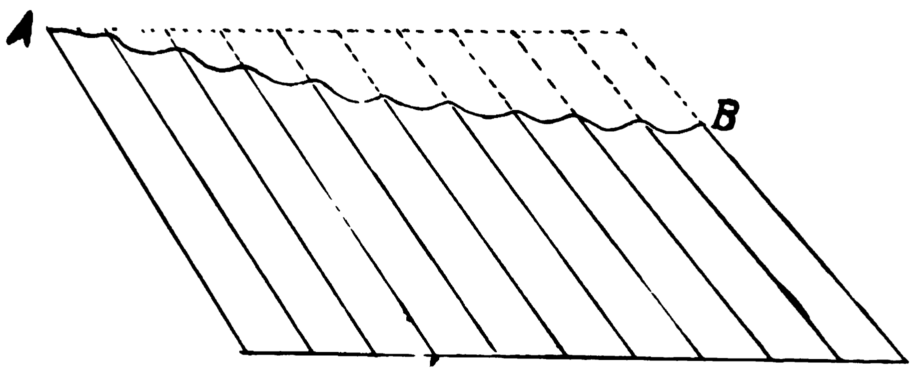


Figure 2.- Rôches Montonnées topography. No. 71, Weber canyon. The inclined lines represent the dip of the beds, the line A.B., the topography of the bottom of the canyon for a distance of about two miles.

the range. The beds dip west of north at an angle of 35 to 40 degrees. The out-crop of the ledges is therefore upstream and as the ice came down the canyon they were cut down but not entirely leveled so that now they have a rolling appearance, and one ascends the canyon as if going up a flight of stairs in which the steps are very broad as compared with their height. (See figure 2.) This topography continues to the head of the canyon. The cols leading into the Provo basin, elevation 10,400 feet, are heavily striated and glaciated. Examinations on the side of Mt. Watson showed that the upper limit of ice was about 10,800 feet.

The catchment basin is about six square miles in extent and is in reality part of the one large collecting area for snow from which ice moved down the Weber, the Provo, the Bear, and the Duchense rivers.

As would be inferred from the above discription, the work done by the ice in this canyon was very considerable. Not only was the loose material carried almost completely away, but the solid quartzite ledges were ground down and at the same time the bottom of the canyon widened from its previous form to the broad U-shaped form which it now has.

Some small lakes occur in the head of the canyon but they are far less numerous than in the Provo basin. This lack of lakes is probably due to the perfect cleaning out

which the canyon has experienced. No drift has been left by the receding ice to form basins into which the water might collect. In this connection it is well to note that the number of lakes in the basins on the north side of the range is , in general, less than the number in similar basins on the south side.

Basin 72. - This branch is about seven miles long. It heads directly north of Bald Mt. but gives off a small tributary to the right about two and one half miles from its head. It has an average gradient of a little less than 300 feet per mile, though the upper part is much steeper while the lower part is less steep than the average.

This tributary differs markedly in appearance from 71. In place of a bare rock floor with only a scattering timber growth, there is a good soil covering and a growth of trees, brush, and underbrush so dense as to render travel very laborious. The walls are steeper and the bottom narrower than in 71. Near the head, however, when the canyon broadens into a cirque the bed rock is exposed in abundance and shows all the polishings and striations mentioned in 71. Rock basin lakes (See Plates III.- IV.) are abundant and in some instances nestle so close to the mountain that the talus slopes actually reach the water. The area of the basin is about four and one half square miles.

The depth of the ice at the lower end of what I have called the basin was something like 1,700 feet. On the right only one narrow ridge about one mile long, between this canyon and 71, projected above the ice. This ridge, as seen from the map, is 2,000 feet above the stream bed and has an elevation of 11,000 feet. On the left hand side similar conditions maintained. Only three small peaks between this canyon and the head waters of Hayden Fork of Bear River reared their heads above the snowy mantle. The long flat ridge between 72 and 73 was certainly covered with névé and would correspond with what Matthes calls a nivated region since there seems to have been no movement of ice.* At the head of the cirque the ice was continuous over the cols lettered a, b, and c, with both the Provo and Duchense ice masses, as shown by the glaciated rock surfaces on the very summit of the divides and by rock basin lakes so near the summit that, if one makes a guess from a distance as to which way they discharge their waters, he is as apt to be wrong as right.

The upper limit of ice marking as determined around the peaks a and b, e and f, was 11,000 feet. At f good striations are observed at this elevation. Above this line the peaks are very steep and consist essentially of a mass of huge angular blocks.

* Twenty-first Annual Report of the U.S.G.S. Part II. - Glaciation of the Bighorn Mountains.

It is evident from the above that there must have been a considerable thickness of ice and névé above the 11,000 foot contour in order to furnish the necessary pressure to produce movement, and force to accomplish the work of glaciation in so perfect a manner. What this depth was we have no means of knowing but it was probably not less than a hundred feet.

Basin 73, or Fish Lake Canyon. - This is the easternmost basin of the Weber. Leaving that canyon at Holiday Park, it takes a south-westerly course and ends in a broad basin about six miles beyond. The canyon forks a little less than half way from its mouth to its head. At the head the two forks practically unite again to form one large basin. The bottom of the canyon varies from an eighth to a quarter of a mile in width. In a distance of five miles the gradient of the stream is 2,000 feet, or 400 feet to the mile.

At the very intrance to the canyon a lateral moraine skirts the mountain on the right hand side at an elevation of 300 feet or more above the stream. The left hand side is steeper and the drift has not lodged there to so great an extent, but still there is sufficient to show the presence of ice at a former period of time. About one mile farther up a terminal some fifty feet high crosses the canyon, the material of which is boulders, sand and clay .

Opposite this moraine, the peak, lettered A. on the map, on the right hand side of the canyon, juts up as a sharp round prominence about 300 feet above its surroundings. This knob was the only part of the mountain which was not covered with ice. A half mile above the terminal several small terraces succeed each other on the right hand side of the canyon, These mark the position of the side of the ice during the stages of its retreat. The divide between the two forks, like the mountain to the right, was covered with ice except two small peaks out at the end of the nose. The bottom of the canyon is everywhere covered with drift to such an extent that the bed rock is no where exposed.

The basin at the head of the canyon is about one and one half by two and one half miles in extent, is semi-circular in outline, and bordered by a very abrupt steep face at the head. Only at the very head of the basin is the bed rock exposed. Everywhere else the covering of drift is very deep and the topography of the drift very rolling. There are some half dozen lakes all shut in by moraines which extend in a direction transverse to that of the canyon. Two especially large moraines, from 125 to 150 feet high and one half mile long, cross the basin below Fish lake. The outermost of these is composed entirely of huge blocks of bare rock without a vestige of soil or vegetation.

Ice spread over the mountains surrounding the basin to the right and left to an altitude of nearly 11,000 feet . There was thus a connection between the névé of this basin and that of the East Fork of the Weber on the right and the Hayden fork of Bear on the left. The slope of the ice was something like 1,700 feet in 6 miles, or a little less than 300 feet to the mile, more than 100 feet less than the gradient of the present stream. The thickness of ice where it rounded peak A. was about 1,000 feet.

The one significant feature in this canyon which has any bearing on the question of epochs is the second moraine of angular quartzite blocks below Fish Lake. This moraine, though differing in material and size of boulders is similar in aspect to one later to be described in connection with the middle Fork of Blacks Fork. As already stated the material of the moraine consists of large angular boulders perfectly bare of soil and barren of vegetation. Scarcely more than a quarter of a mile above this moraine just described is one of similar dimensions but presenting a very difference appearance. Instead of bare angular blocks of stone, there are subangular and more or less rounded boulders, and intermixed with these, enough soil and fine material to support a rather meager vegetation. Accordingly scattering pine trees and varieties of mountain brush are distributed over the moraine. Below

the bare terminal moraine there is much till in the canyon composed largely of soil and fine detrital material , covered with a very heavy growth of timber. The moraine of bare angular blocks seems then to be somewhat of a freak. After carefully examining it and contrasting it with the one above and the till below, the only conclusion that seemed at all satisfactory to myself and others present was that this moraine marked the outer limit of a second ice advance. If it were formed by the retreat of the first ice sheet we could see no reason why the blocks of stone should be more angular than those in the till in the canyon directly below or the moraine above; neither could we see why it should not contain an equal amount of fine material and soil and hence be covered with vegetation. The till is perfectly normal and was of course deposited by the retreating ice. When the ice disappeared from the basin normal weathering would follow and a great amount of talus would collect, as it is doing at present at the base of the steep cliff-like rim which encircles the basin. A great pile of talus is accumulating at present along the cliff facing the lake, so much so that it is rolling down to the very edge of the water. If after material had accumulated in this way for, no one knows how long, another glacial period less prolonged than the first came on, it could have very easily carried before it

enough angular material to form the moraine in question, which would necessarily mark the maximum extension of the second ice sheet in this canyon. We must now account for the moraine above the one just discussed in which the boulders are more rounded, soil is present, and on which some vegetation is growing. In the first place it is to be noted that the soil and vegetation on this upper moraine are very meager when compared with that of the normal till below the lower moraine. It is but natural to suppose, in deed it is beyond supposition, that only the material which did not get under the ice escaped wearing and abrasion; therefore with the exception of the material which fell on the top of the ice, only that which was pushed out before it would escape the wearing and consequent tendency to rounding. There would also be some fine detritus found by the attrition of the material under the ice. Therefore, if after pushing up this pile of loose angular blocks to form the lower moraine, the edge of the ice retreated to the position of the second moraine and there halted for a time it would build up a moraine of boulders which had been more or less rounded by grinding beneath the ice, and mixed with these a part of the fine material resulting from the attrition, and thus we would have formed a moraine corresponding to the upper one under consideration. It is frankly admitted that the above is simply a theory the

actual proof of which cannot be demonstrated, but it seems the only explanation that fits the case. In another place we will meet with another moraine of very similar aspect to the one of angular blocks just discussed, and there it will be shown conclusively that two separate ice advances must have occurred. This fact adds some weight to the above theory.

In thinking of Weber canyon with respect to glaciation we can picture to ourselves four ice lobes moving down four similar canyons as distributaries from a continuous névé field and converging to form one trunk ice stream at Holiday Park about six miles from the crest of the range. The thickness of the combined ice at the park was about 1,500 feet.

As already mentioned lateral moraines skirt the wall of each tributary canyon far up on its sides and finally cover the intermediate divides forming, on the down stream end of the latter, medial moraines. The depth of moranic material is not great which shows that the work of the ice was principally that of degradation rather than aggradation. Following down the canyon from Holiday Park the elevation of the lateral moraines gradually decreases until at Smith and Morehouse canyon they lie well down on the base of the mountains and a few miles beyond a long ridge in the valley parallel to the stream and separated from the mountains by

a shallow depression indicates that the end of the glacier was not far below. Just where the terminus was is diffi - cult to say since there is no terminal moraine, but it was probably less than three miles above South Fork. The total length of the glacier was thus about eighteen miles.

The material of the moraines consists of fine detritus, resulting from the abrasion of the quartzite rocks, mixed promiscuously with rounded and subangular stones of the same material varying in size from sand and gravel to large boulders several feet in diameter. There is no means of determining the percentage of material that came from the crest of the range as compared with that picked up by the ice farther down in its course, since there is no lithological differences upon which to base estimates.

Curiously enough, although striations are so abundant and well preserved on the bed rock in the heads of the basins, it is exceedingly rare that one finds a striated boulder. Why this should be the writer has not been able to determine.

Below the lower limit of the ice a valley train stretches down the canyon for about two miles, giving the canyon the U-shape form of the glaciated portion. Below this the canyon narrows rapidly as is well shown on the topographic map, and near the mouth the U-form gives way to the V-form characteristic of mountain gorges. Where the stream issues

from the mountains its bed is so narrow that a dugway had to be constructed before the canyon was passable for wagons. Farther up the bottom is so flat and open that no road work was necessary.

The amount of post-glacial work done by the stream is very slight. Nowhere has it cut its channel into the bed rock more than a few feet. In the cirques and along steep overhanging cliffs very considerable accumulations of talus have formed as a result of the various forces of weathering. It would seem that the latter have greatly predominated over the streams in the amount of post-glacial work performed.

Data bearing on epochs has been discussed in connection with Smith and Morehouse and Fish Lake canyons. In the main canyon there is no very characteristic evidence except the relation of the laterals to the terminal from Smith and Morehouse canyon. Some small terminal moraines cross the canyon just below Holiday Park and others still lower down but they are not significant of anything more than a brief halt in the recession of the ice.

Bear River.

West Fork. - This is the next canyon east of Weber. It unites with the main Bear two and one half miles south of the Utah-Wyoming boundary line and follows a southwesterly course for about thirteen miles giving off to the right several tributaries. The stream follows close to the base of the long, narrow, low ridge which separates this canyon from the Hayden fork of the Bear, and therefore lies well on the east side of the canyon. The canyon does not reach the crest of the range but takes its head among the lower peaks to the north of Fish Lake fork of Weber . The grade is low, about 147 feet per mile.

In the upper part of the canyon the material is Uinta quartzite and Carboniferous limestone but to the north of the road which crosses the divide between the Bear and Weber the red beds of the Triassic come in.

The canyon is significant for its very broad open form.

The cirque or nèvè basin was of vast extent for its comparatively low altitude. Beginning at the stream head on the east at the point marked E. on the map it curves away around to F. at the northwest. This basin strongly contrasts with most others in the amount of till present. The area over which the ice spread is large and the work done seems to have been deposition rather than erosion .

Till is everywhere abundant. No rock bottom lakes are found, those that do occur occupy depressions in the ground moraine. The upper limit of the ice did not exceed 10,000 feet and in general was somewhat less.

Passing down the canyon we find a distinct lateral moraine skirting the divide to the east and finally completely covering it at about the point G. (9,600 feet). To the west no lateral occurs but everywhere ground moraine. It appears that the ice, being less confined in this direction, had just flattened out and dropped its material on melting without producing any lateral moraine. Down the river, the last five or six miles of its course before it unites with the main stream, is the most characteristic pot and kettle topography exhibited anywhere in the region.

The great development of till in this canyon seems to be accounted for by the fact that as soon as the ice left the high peaks at the head of the basin it emerged upon the unconsolidated Triassic, capped by the still more loosely cemented Wyoming conglomerate. This latter still caps the hills in the vicinity of F. This material was doubtless dissected by erosion channels prior to the advent of the ice and hence fell an easy victim to its ravages. The ice probably became overloaded and hence at every little obstacle encountered, material was deposited and thus was developed the undulating, pitted, ground moraine which is so

peculiar to this canyon and Mill Creek, later to be discussed.

On an east-west line through the point G. there was a continuous ice sheet from F. eastward to the eastern boundary of East Fork of Bear, a distance of some fourteen miles. A few miles farther north this sheet extended much farther east covering all of Mill Creek basin but diminished somewhat in its westward extent. By the coalescence of the West, Hayden, Still Water, and East forks of Bear River, and Mill Creek there was formed a small piedmont glacier whose maximum width was something like fourteen miles.

Hayden Fork of Bear River. - This canyon lies east of the West Fork. From its junction with Still Water Fork to the head of the canyon is a distance of about twelve miles The canyon heads in the crest of the range and from it the traveler passes over into the head of the Duchense, on the south side of the mountains, through a low col or saddle as they are sometimes called. On the east side of the canyon and about one mile from the head rises Hayden Peak, 12,500 feet high, which is the highest peak in the west end of the range. Through tributary 13 the canyon is connected by means of two lows cols, e and f, with the head of Weber canyon. The gradient of the canyon is low, except at the very head, and the bottom broad and open. (See Plate II.)

The cirque proper is about two and one half miles wide by three long and in it the ice recorded its presence by polished rock surfaces at an elevation of 11,000 feet. The basin is rather free from drift. In it the beds of quartzite are bare and present the usual polished and striated surfaces. Small rock-basin lakes occur near the head of the cirque.

Passing down the canyon the lateral moraine is well out lined on the west side but only distinguished at intervals on the east side which is steep and precipitous. About three miles from the head of the canyon a few small terminals are crossed. No. 13, near its junction with the main is entirely choked up with a terminal which has diverted the stream from its old channel causing it to turn rather abruptly to the east and join the main higher up than it formerly did.

Down the canyon about two miles farther is another series of more prominent terminals about one half mile in width. Behind such terminals there is always a patch of meadow covering the site over which the water formerly flooded. Just below these terminals at an elevation of about 9,800 feet the ice spread over the hill to the east and united with that of Still Water Fork. At a slightly lower level it merged with that of West Fork as previously indicated. The terminal ends of these divides are deeply buried with medial moraines. The maximum thickness of

the ice at the point where the streams merged was between 800 and 900 feet.

Still Water Fork. - Still Water Fork heads in the crest of the range in a broad, semicircular, amphitheatrical basin at the head of which stands Mt. Agassiz.

The basin is tri-lobate, the lobes being separated by long narrow ridges. The area covered, including the projecting noses, is something like twenty square miles. The bounding rim is very steep and precipitous. To gain the crest from the Still Water side would be a very arduous task but from the Duchense side it is easily accomplished.

This basin is in all respects similar to that of Haydan Fork and shows the same characteristic polished and striated surfaces. The upper limit of the ice was 11,000 feet. In contrast with the canyons thus far considered, the crest of the divide at the head of the basin was not glaciated but was undoubtedly covered with névé.

Passing down the canyon we have a more perfect devel - opment of lateral moraines on both sides than has previously been met with. Some idea of the prominence of these lateral moraines can be best obtained by referring to Plates VII and VIII. Where the canyon begins to narrow they stand out as regular table-lands on the mountain side at an elevation of 1,200 feet above the stream. A cross section of the canyon at this point would have the form

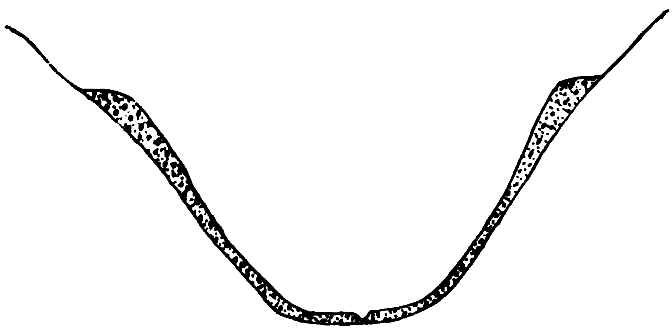


Figure 3.- An ideal section showing lateral moraines on the sides of the canyon and till in the bottom.

shown in figure 3.

Another feature not met with before, but, as we shall see later, common in the canyons to the east, is the blocking up of the tributary canyons by the lateral moraines from the main canyon. No. 30 is typical of such blocked up tributaries. A dèscription of it will suffice for all such occurrences and hereafter they will simply receive passing mention.

The lateral from the main canyon cuts across 30, as indicated on the map by the green lines, so that from a distance the bottom of 30 appears to be as high as the top of the moraine. Examination of the canyon shows this not to be the case. The bed of No. 30 is as near the bottom of the main canyon as tributaries usually are. Like the main canyon it has the characteristic U-shape and has, like it, been occupied with ice. A deep V-shaped channel has been cut through the obstruction by the tributary stream.

In almost everycase where such an occurrence is found, the lateral of the main canyon is slightly higher than immediately above or below.

The most probable explanation for this damming up of the tributaries is that these canyons, being very small as compared with the main canyon, gave birth to correspondingly puny glaciers. The movement of the large glacier would be rapid and vigorous as compared with the small

one, hence when the latter encountered the former, instead of pushing straight out into the main canyon and thereby keeping its mouth open, the small glacier was deflected in the down stream direction of the large one, the two moving approximately parallel. Because of this deflection a sort of medial moraine was banked across the mouth of the tributary canyon. This would also explain the increased height in the laterals of the main, opposite these tributaries.

Another possible explanation of the case is that the damming of the tributaries was done by a second advance of ice in the main canyon in which the tributary did not participate, or in which it only feebly participated, and hence did not reach the main canyon. Of this there is no absolute proof, hence it seems best to consider the first explanation as the proper one ; for it accounts fully for all the phenomena observed. Plate V, is a photograph showing one of these tributaries.

About two and one half miles above where Still Water unites with Hayden Fork a very heavy terminal crosses the canyon and to this fact the canyon owes its name. For several miles above this moraine the canyon bottom is swampy and the stream winds back and forth in broad curves like a stream at grade. (See Plate X, taken from another canyon.) Evidently at one time a great lake existed behind this

barrier, but the concentrated efforts of the water have at last succeeded in cutting through the obstruction and now in place of the lake we find a grass grown marsh.

East Fork of Bear River. - This is the easternmost drainage system, from the crest of the range, whose waters finally reach Great Salt Lake. Blacks Fork, the next canyon to the east, is tributary to the Green River.

East Fork of Bear is about twelve miles long. The side walls are steep, almost vertical in places. About three and one half miles from the head, the canyon bifurcates. Below this the bottom is about a quarter of a mile wide but above the forks it is narrower. In either fork the cirque is small as compared with most of the other canyons. There is little development of till and the usual bare, polished rock surfaces. Lakes are almost wanting. Lateral moraines are well developed on the west side of the canyon, where there are also several obstructed tributary valleys. On the east side the walls are so precipitous, until the mouth of the canyon is approached, that the laterals have not remained.

About three miles above the forks there is a very heavy terminal corresponding to the one in Still Water. The stream, which is much larger than that in Still Water, has cut a channel some thirty feet deep in this moraine. On the up-stream side of this terminal in the exposed

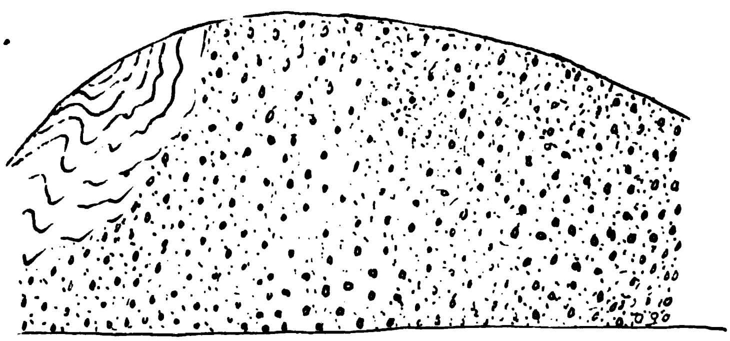


Figure 4.- Contorted stratification in till, East Fork of Bear River.

river bank is a beautiful illustration of contorted stratification in till, shown roughly in figure 4. The contorted laminae are composed entirely of very fine sand free from pebbles. The appearance is as if, after the edge of the ice had retreated from the position in which the terminal was formed, a deposit of fine alluvial sand collected behind the moraine. After this the ice advanced again and on reaching the stratified deposit crowded it up against the moraine whose resistance caused a doubling up of the fine plastic material.

Between East and Still Water forks where the two ice streams met they piled up a heavy deposit of moranic material. When the ice began to lower, it separated along this medial portion and its successive halts are marked by ridges parallel to the medial and separated from it and from each other by depressions. The same feature occurs, but to a less marked extent, between each two of the other forks discussed. In the depressions, lakes form during the wet season but are usually dry before the close of the summer.

Passing now to a discussion of Bear River canyon as a whole we have seen that each of the main tributaries has been the scene of rather extensive glaciation, that the upper limit of ice in each case was approximately 11,000 feet, with no very accurate data for determining the

amount of névé above. We have also seen that near the mouth of each tributary a more or less conspicuous terminal moraine was developed. From these terminal moraines outwash plains, shown on the map by the parallel green lines, invariably proceed, which become broader and more broad as successive ones unite, till finally, at the junction of the West Fork, the valley of the Bear is fully a mile and a half wide. This outwash plain is very level for a mountain stream and, while it contains many large boulders, shows rough assortment of material. On either side of the valley we still have unassorted ice deposits which continue beyond the Utah- Wyoming line where the terminal for the maximum extension is found. In this outwash the river has cut its present channel to a depth of ten to fifteen feet and is still working in the same material. It is evident that when the ice edge stood at the inner set of terminals, it must have remained there for a considerable length of time. It must also have been heavily loaded with debris to furnish the material represented in the terminals and the outwash plains.

Occasionally in these outwash plains, especially near their outer margins, one finds small mounds rising above the otherwise level plain. These mounds appear to be the tops of small hills which have been partly buried by the outwash train.

The mounds themselves are of glacial origin. The conclusion is that prior to the outwash of the valley trains and therefore prior to the formation of the terminal moraines from which they proceed, that part of the canyon now occupied by the valley train, was occupied by till with an undulating topography; that with the outwash of the valley train this undulatory topography was largely obliterated, partly by a filling up of the depressions and partly by a cutting down of the swells; but that some of the swells, principally those near the outer margin of the waters which formed the outwash plain, were not cut down , neither were they completely buried. In addition to the partly buried mounds of till there is sometimes found a relation of valley train and lateral moraine which indicates a lapping of the valley train over the lower part of the moraine. Instances of this kind are perhaps better shown in Blacks Fork than in Bear River canyon. The terminal moraines which mark the maximum extension of the ice are almost always less in tact than the inner set of terminals from which the valley trains proceed, a fact which suggests at once the greater age of the former.

To account for the facts given above,one of two things must have occurred; (1) during the retreat of the ice it must have halted for a very long time at the position occupied by the inner terminals, or (2) after the retreat of

the first ice sheet there must have been a second advance, and this inner set of terminals marks the maximum extension of that advance. It then becomes a question as to which of these two possibilities best explains the facts. So far as the relations of the valley trains to the partly buried mounds and to the lateral moraines formed by the maximum extension of the ice, between which the valley trains extend, are concerned, either of the above cases will apply equally well. Whether the ice stood at the inner set of terminals for a long time during the general retreat of the first ice sheet, or whether it stood there for the same period of time during a second advance, the facts would remain the same. There would have been water issuing from the end of the glacier which would flood the canyon below, carrying with it much of the material that was being constantly dropped at the end of the ice. As this material was deposited lower down in the canyon it would fill up the depressions and cover, or partly cover, the swells in the ground moraine left by the retreating ice; and thus in either case we might find some partially buried mounds. In the same way, where the material was deposited in contact with a lateral moraine, the former would lap up over the latter. Along these two lines, then no inference can be drawn either one way or the other. The ice might have been retreating or it might have been at the position of maximum advancement.

When the time element is considered in connection with the two possibilities given above there is little more evidence for drawing conclusions one way or the other than in the cases discussed above. If there be any preponderating evidence in either direction it seems to me that that evidence is in favor of a second advance of the ice. If the inner set of moraines were formed by a halt of the retreating ice of a first advance, that halt must have been a very prolonged one. Indeed, it must have been longer than all the other halts above and below these terminals combined. I am perfectly safe in saying that the material represented in these inner terminals and the outwash from them is much greater than that represented in all the other terminals combined, the one of maximum extension excepted. Between these inner terminals and the outer ones, evidence of halts in the retreating ice sheet are very meager and when present they indicate only a brief stay in the general retreat. Above the inner set of terminals the evidences of halting in the retreat of the ice are very numerous, but they invariably point to a very brief one as compared with that represented by the inner set of terminals. Why should the halt of the receding ice sheet be so much greater at this point than at any other place where a halt was made, or than all the others combined ? The only answer is that the melting of the ice was balanced by the

downward movement for a greater length of time. In other words, the conditions which maintained while the ice was at its maximum extension were repeated, though for a somewhat less length of time. It seems more rational to the writer to attribute the repetition of these conditions to the coming on of a second glacial climate after the dis - appearance of the first, rather than to a rejuvenation of the ~~[illegible] condition of the~~ latter.

Concerning the apparent age of the outer and inner set of moraines, the latter certainly appear the more recent. As already stated, they are undissected by erosion and with the exception of the narrow channel cut out by the canyon stream are apparently in an undisturbed condition.

From the above argument it is seen that in so far as there is any preponderating evidence in favor of one of the two possible explanations,- that is, that the inner set of moraines was formed by a halt in the retreat of the first ice sheet or by the advance of a second - that evidence is in favor of a second ice advance and therefore two ice epochs. But it is admitted that the evidence is not con - clusive.

The lower limit of ice was at an altitude of about 7,500 feet, its total length, as stated, twenty miles.

Post-glacial erosion has been very slight when com - pared with the vast amount of work done during and before the ice epoch.

Mill Creek.

This canyon, as will be seen by reference to the accompanying map, runs nearly parallel to the Bear at the north edge of the map, uniting with it some distance beyond. Farther south it swings around almost directly to the east and gives off several branches, both north and south. It has the appearance of a large scoop with the handle down stream.

The material is Triassic capped with Wyoming conglomerate which covers Concrete plateau encircling the head of the canyon, and occurs again on Mt. Elizabeth to the north and on Dead Man's Mountain on the south west. An exposure of this conglomerate so much resembles till that in the absence of striations it is very difficult to distinguish from a till deposit.

Mill Creek was occupied by ice but is important only in showing the effect of different materials on the topography of glaciated regions. As in the West Fork of Bear, there is a great development of till with a very undulating topography. This development of till seems to be wholly due to the presence of the less resistant Triassic and younger formations. The till supports a very dense growth of timber.

Black Fork.

Passing up Mill Creek the road, which is very good in the lower part, finally fades into a mere blazed trail through the dense growth of timber. After riding for about two hours through timber so thick that the rays of the sun scarcely penetrate, the traveler reaches the summit of a broad, flat-topped divide known as Concrete plateau, so named from the great development of Wyoming conglomerate which caps it. This divide forms the water-shed which separates the drainage basin of the Green River on the east, the waters of which finally reach the Pacific Ocean, from that of the Bear River on the west whose waters finally discharge into Great Salt Lake. We look from here down into Black Fork canyon and a scene of grandeur presents itself to view.

Looking directly south the eye follows a mountain defile, shut in on either side by massive walls 2,000 feet high, which leads directly to the heart of the range where the snow drifts of the previous winter linger upon the mountain side glistening in the noon-day sun and forming a pleasant contrast to the sombre effect produced by the green of the trees mingled with the gray, brown, and red colors of the rocks.

Directly below us, almost at our feet, is a beautiful lake of clear water which we cannot yet see because the

dense timber and a prominent ridge, which proves to be a moraine, hold it within their bosom.

At the point where we descend the hill two large forks known as Middle and East forks, are given off to the left. From the forks, Black Fork is about fourteen miles long to the head. In its first five miles the canyon is broad and open and the side slopes rather gentle. Above this the walls become steep and precipitous and the canyon narrows in considerably, though still retaining a distinct U-form.

At the head this defile broadens somewhat to form a cirque (shown in Plate VI.) one and three fourths by one and one half miles in extent. The basin is crescent shape and bounded on all sides by almost vertical and unbroken walls of red and green shale, interbedded with the different varieties of quartzite common to the region. Ice stood at an elevation of 11,300 feet and névé probably covered the col at L., connecting Black Fork névé field with that of East Fork of Bear River. The bottom of the cirque, near the head, is strewn with a considerable thickness of till which has a decidedly hummocky topography and in which are a few small lakes. This material must have been dropped by the ice at its final disappearance, for everywhere else in the upper portion of the canyon erosion has been the work of the ice sheet. A rock terrace one fourth of a mile wide skirts the mountain on either side

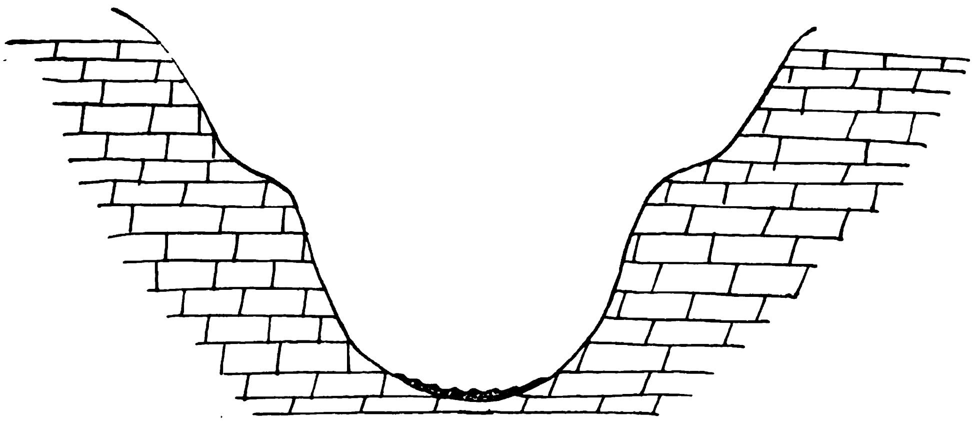


Figure 5.- A cross section of Blacks Fork near the head, showing the well developed rock terraces of glacial origin with slight dribbling of till in the bottom. of the canyon. The terraces are fully two hundred yards wide at the point for which the section is made. The rock is Weber quartzite.

of the basin and extends down the canyon, though less prominent, for several miles. The elevation of this terrace varies from something like two hundred feet above the stream at the head, to eight hundred or a thousand feet at its lower limit. A cross section of the basin is given in figure 5., and Plate VI. is a photograph which shows the terraces in a most distinct manner. This terrace is smoothed off almost like a floor and is striated in a most beautiful manner, as are also the side walls below the terrace.

The small tributaries which enter the upper part of the canyon from the west have their beds corresponding with the upper level of the terrace, over the edge of which their streams cascade into the main stream below.

Passing down the canyon the rock terrace seems to be replaced by a lateral moraine which encloses the tributary valleys as in Bear River canyon. Tributary 38 is a canyon of this kind. It is to be noted that the great fault along the north face of the range, which brings the Triassic beds in contact with the Carboniferous, crosses the canyon just above 38.

As previously noted, wherever the Triassic material is encountered deposition seems to replace erosion. The laterals continue down the canyon on either side and when the low rolling hills are reached just above the forks, two

two sets are discernable. The lower of these closes in to form a broad distinct terminal whose lower limit is about opposite the mouth of Middle Fork. The upper set spreads out, those on the east connecting with Middle Fork to form a medial, and those on the west flattening out more in the form of a ground moraine which extends over the low divide into West Fork. Most of the debris carried by the ice seems to have been deposited on the Black Fork side of this divide.

The topography is of the ground moraine type and several lakes are formed in the depressions. From the terminal which crosses the canyon an outwash train extends down stream uniting with similar outwash from similarly situated terminals, from Middle and East Forks. These outwash trains are identical in every way with those in the Bear River canyon which have been described and discussed above. Other small terminals occur a few miles farther up the canyon.

Middle Fork of Black Fork. - This canyon is limited in extent as compared with the other two forks of Black Fork. At the head stands Mt. Tokewana, 13,200 feet high. The side walls are not distinct as in the other canyons but rather fade away in a series of rolling hills. The basin is well cleaned out and presents the usual glaciated

appearance. The upper limit of the ice was 11,500 feet. The small tributary on the left along which the trail, indicated by the dotted line, leads over into East Fork , curiously enough was not glaciated. This seems to be another instance of a nivated canyon as distinguished by Matthes.

The most significant feature in Middle Fork attaches itself to a moraine which, in the nomenclature of Dr.Chamberlain, is described as a push moraine. This moraine lies about two thirds of the way down the canyon. It consists entirely of lime-stone in huge blocks, often twenty or thirty feet square, which are practically unaffected so far as rounding and polishing are concerned. There is practically no fine detritus in among these huge rock masses. A very cursory examination reveals the source whence this material came. On the east side of the canyon and less than a fourth of a mile up stream is a prominent peak capped with limestone, presenting a bold cliff-like face to the south and west. Crossing the canyon on a diagonal line a little north of west and passing south of the limestone peak runs the great fault which is easily located by the upturned, almost vertical edges of the Triassic. Careful examination shows that there is no other limestone near..This peak then has furnished the material of the moraine and the blocks of the latter can actually be traced

curving right around up the hill-side to the cliff. On the other side of the canyon the moraine extends some two hundred feet up the gently sloping hill-side.

With regard to the stage of ice movement in which this moraine was formed there are but three possible assumptions: (1) that it was formed by the first advance of the ice, (2) that it was formed by the retreat of the first ice sheet during one of its halting periods, (3) that it was formed by a second advance of the ice subsequent to the retreat of the first advance. Each of these three possibilities will be considered in order.

1. That the moraine was formed by the first advance of the ice.- We know that during its first advance the ice moved two and one half miles farther down the canyon to its junction with the main fork, and there remained sufficiently long to build up a terminal moraine very many times larger that the one under consideration. Further, it is very probable, indeed almost certain, that the ice in its first advance did not stop at the position now marked by the moraine at the mouth of the canyon, but on the contrary united with the ice in the main canyon, down which it moved several miles. If this Push moraine had been formed by the advance of the first glacier it would have been destroyed by the further advance of the ice which built it. Therefore, since the moraine in question does not occur at

the maximum extension of the first ice advance, it could not have been built and preserved as it is by that advance.

With regard to the second possibility; viz., that the moraine was formed by the retreat of the first ice sheet during one of its halting periods, let us consider:- (1) the effect of the <u>advance</u> of the ice on the <u>talus</u> at the foot of the limestone cliff from which the material for the moraine in question was derived, (2) the effect of the ice on the <u>cliff</u> itself.

(1) The effect of the advance of the ice on the accumulated talus.- During the unknown ages that elapsed between the erosion of the canyon and its occupancy by the first ice sheet, a great amount of talus would have accumulated at the base of the cliff in question. This talus was in the direct path of the advancing ice and was in no condition to maintain its position before so great a force. Therefore, when the ice encountered the talus pile the latter must have been borne away by the former, either before it or beneath it, or both. It is not the idea that the loose material was all picked up at once by the ice, as a handful of pebbles by a school boy, but there seems no escape, in the mind of the writer, from the supposition that long before the ice had begun to retreat from its position of maximum extension, as outlined above, all loose material in the bed of the canyon would have been carried

away and the ice would have been working on the bare rock floor. That being the case, so far as the talus is involved in the story, there would have been none at hand out of which the moraine might have been formed by the retreating ice. But if we admit for sake of argument that some of the talus might have remained near where the ice found it, and thus have been available at the retreat of the ice , we cannot concéive that it would not have been highly glaciated by the quartzite material from the head of the canyon, contained in the over-riding ice mass. But the rock masses in the moraine show no striations or polish - ings, hence we are forced to conclude that the moraine was not formed by retreating ice from talus material accumulated at the base of the cliff.

(2) Let us now consider the effect of the advancing ice on the cliff itself. When the ice first advanced it would find the cliff in the most favorable condition for attack. Joints and fractures would have cut its face into blocks of various sizes and there would probably have been numerous overhanging masses, the counterparts of their fellows in the canyon below. These rocks would have been easily rent from the cliff by the advancing ice, and because of this very ease of dislodgement would be removed during the earliest stage of the ice invasion. As the action of the ice on the cliff continued, the readily available material would continually decrease, the irregular-

ities of outline of the cliff face would constantly diminish until finally the only source of large blocks would be the part of the cliff which projected above the ice , and which would have still been exposed to the ordinary forces of weathering. But a reference to the map will show that the portion of the cliff above the ice was very small and hence would not yield a very large amount of material. Therefore at a very early stage in the glacial history the amount of large angular blocks available would be very small. On the other hand, the proportion of fine detrital material carried by the ice would increase at least up to a certain limit, directly as the length of time of ice action.

The only possible conclusion is, therefore, that a moraine built up by retreating ice would consist of boulders almost universally rounded, more or less, and ice-worn, mixed with a considerable amount of fine detritus. The boulders of the moraine in question are not ice-worn or striated and with them there is practically no fine material. Hence the moraine could not have been formed by retreating ice. Since the first two possibilities cannot be used to explain the existence of this particular moraine, the third and only other possible explanation might be considered as established. We will see how the facts fit the case.

The third hypothesis is that the moraine was formed by a second advance of the ice after a period of absence of ice and normal weathering sufficiently long to admit of the accumulation of a fresh mass of talus at the base of the cliff, and the consequent re-establishment of a jointed and fractured irregular cliff face. We saw in considering the first hypothesis, that the only objection against it was the fact that the moraine did not correspond to the position of maximum ice extension. After the retreat of the first ice sheet, the cliff would again be exposed to the normal forces of weathering which would manifest themselves in the same manner as before the first ice epoch; viz., in the accumulation of talus at the base of the cliff and the development of joints, fractures, and irregularities in the cliff face.

With a long, arid, interglacial period in this mountain region the forces of weathering would have been able to do a great amount of work, and therefore great talus piles would have accumulated again at the base of prominent cliffs. A practical illustration of this fact is found in the great talus piles at the bases of all prominent cliffs in the same region today, which certainly have accumulated since the last disappearance of the ice. With this talus material and the blocks broken from the face of the cliff by the ice itself, an advancing ice

sheet could form a terminal moraine of angular blocks with little detrital material , provided it did not move far beyond the place where the talus had accumulated, thus destroying, more or less, the angularity of the rock masses and increasing the amount of detrital material.

Since the moraine in question is undoubtedly a terminal moraine, since it is composed of angular blocks, unglaciated and with little or no fine material, since it could not have been formed by the first advance of the ice sheet which extended much farther down the canyon, since the nature of the material unquestionably forbids that it was formed by a retreating ice sheet, and since the moraine could have been formed by a second advance of the ice after a long period of weathering and accumulation of talus, we must conclude that the moraine was formed by such a second advance of the ice after a long interglacial period, during which the processes of weathering were active, and the interglacial period was sufficiently long to admit of the accumulation at the base of the cliff, of the talus of which the moraine is composed. In other words, this moraine is conclusive evidence of two glacial epochs separated by a period of ice absence.

To summarize, there must have been a first advance of the ice during which the outer moraine was built. There must have followed a period marked by absence of ice, dur-

ing which normal weathering was in progress. And this must have been followed by a second advance of the ice by which the push moraine was formed.

Nowhere is the recency of the ice work better shown than in this push moraine. The limestone blocks show practically no disintegration. They are as fresh looking as those of the present talus slope.

From the outer moraine the same characteristic outwash extends down stream, uniting with that of the main canyon.

East Fork of Black Fork. - This canyon heads in the crest of the range. About five miles from its junction with the main stream, the canyon forks and forms two very broad, deep gorges extending seven miles farther back into the range.

Each basin, at the head, is well cleaned out, except for a little hummocky till in the bottom. The bed rock shows the usual glacial scorings with the striae parallel to the direction of the canyon. Farther down we find occasional small terminals marking successive halts in the recession of the ice. On the side, the laterals are distinct and stand eight or nine hundred feet above the stream The upper limit recorded by the ice is 11,500 feet. Below the forks, the canyon becomes much more open. About three miles above the mouth a larger terminal occurs from which outwash extends down stream and unites with that from Middle and Main Forks.

Below the main forks, this river terrace, formed of the combined outwash from the terminals of the three forks, extends down stream about three miles. It is more than one fourth of a mile wide and in it the present stream flows in a channel probably twenty feet deep. Occasional mounds of partially buried till occur in the outwash. On the hill sides lateral moraines continue several hundred feet above the stream. These gradually descend toward the stream in passing down the canyon. Near the Utah-Wyoming line a series of terminals close in across the canyon, and about two miles beyond the line, at an elevation of 8,500 feet, the laterals swing in to form the terminal of maximum extension. The terminal, however, is not well preserved.

In this canyon there was a glacier some twenty miles long with a maximum thickness of 1,000 feet.

The amount of post-glacial work, as in previous instances is slight. The amount of glacial erosion, especially in the main canyon, seems much greater than in any previous case.

In addition to the evidence of more than one epoch, furnished by the push moraine in the Middle Fork, there is also the same line of evidence as cited in the discussion of epochs in connection with Bear River canyon. Near the mouth of each of the three forks there is the same charac-

teristic terminal moraine, the same kind of an outwash train extending from them, and the same relation between this outwash and the partially buried mounds and lateral moraines. The discussion given in the case of Bear River canyon (pp. 40 et seq.) is applicable in every particular here and as there is no new feature the argument will not be repeated.

West Fork of Black Fork. - This canyon has participated in the glacial phenomena of the region to a limited extent only. Some ice probably passed over the hill into it from the main canyon and much snow was doubtless blown into it from the broad open top of Concrete plateau.

Lake Fork.

West Fork of Lake Fork. - We cross now to the south side of the range. Beginning at the east margin of our map, we will discuss first the West Fork of Lake Fork. As the name would indicate, there is another fork to Lake Fork which is nearly as large as West Fork.

The canyon heads in the crest of the range directly opposite to Black Fork and its tributaries. That portion of the canyon represented on the map is about fourteen miles long; the entire canyon, however, is nearly thirty miles in length. It is tributary to the Green River.

The canyons on the south side of the range are very difficult of exploration. About the only way to get at them is to get into the heads of the basins from the north side of the range, then get down into the low open country on the south side and work up them as far as they are accessible. The inaccessible part usually takes the form of what is called a "box" canyon. This development is due largely to structure. We have seen that the axis of up - lift is near the north face of the range . As a consequence the dip of the strata on the south side is very slight, rarely exceeding 6° or 8° until the fault line is reached, way out at the margin. In these approximately horizontal strata the canyon descends by steps. Coming up the can - yon from below, one finally finds himself inclosed by

perpendicular walls with a break here and there where a tributary stream enters. Descending the canyon, one arrives at precipices over which he cannot pass. However, from the crest of the range, one can follow along these terraces for a few miles, ascend some commanding peak and get a good view of the situation.

West Fork of Lake Fork presents one of the most magnificent cirques in the range. As seen from the map, it has an extreme width of seven miles and a length of four and one half miles. The basin has been scoured out with a vengeance by the glacier to which it gave birth, but, like the basins on the north side of the range, with the final melting of the ice a light till was deposited over the rock floor. Around the margins of the cirque and along the walls of the canyon, through the narrows, broad rock terraces have been cut similar to those shown in figure 5. The deep inner gorge of the canyon has also been modified by ice action, as shown by the smoothed vertical faces and broad bottom. The tops of the terraces are from 800 to 1,000 feet above the stream.

Lakes are more numerous in the basins than on the north side of the range. This is especially true of the west tributaries 44, 45, and 55. These canyons do not show the scoured out character so prominent in the main canyon. On the contrary they are literally clogged with till. Bed rock

is nowhere to be seen in their bottoms. The topography is extremely undulating and many of the depressions hold water This heavy ground moraine gives rise to an exceedingly dense growth of timber, so dense that it is often very difficult to find one's way through it. An examination of the map will give a better idea than words of the magnitude of the ice in this region. It will be seen that basins 44 and 55 formed one common ice sheet, that both of these and 54 were connected with ice which moved in the opposite direction into Rock Creek.

Detailed work was not done beyond this map but a brief survey showed that the glacier of Lake Fork was about twenty five miles long, and the elevation of the lower limit less than 7,000 feet. The maximum depth of the ice as plainly shown by scoring on projecting noses, was nearly 2,000 feet.

Rock Creek.

Rock Creek is the next large canyon west of Lake Fork. Smaller canyons occur in between which did not extend far enough back into the range to become channels of discharge for the accumulated ice. The topography of these canyons is in striking contrast with that of those which were glaciated.

The cirque of Rock Creek is rather smaller than that of Lake Fork, being about five and one half miles by six in its greatest dimensions. It has the usual semi- circular form and the characteristic ice markings. The upper margin of the ice stood at an elevation of 11,500 feet . The canyon, below the cirque, has the same box form as that of Lake Fork. As already stated, the ice of this canyon was connected with Lake Fork through Nos. 60 and 61. To the west a large lobe of ice extended over the Grandaddy Lake district and from here there was a continuous ice sheet, with only here amd there a projecting nunatak , extending westward over the Duchense and Provo basins, connected also with the Weber and Bear River basins on the north side of the range.

The Grandaddy Lake basin is very similar in appearance to that of Brown Duck Lake of Lake Fork. There is the same abundance of till with the same hummocky topography. Lakes are so numerous that it is almost harder to avoid them

than to find them.

About one and one half miles up the canyon from the edge of the map a heavy terminal occurs, and from it extends an outwash plain similar to those described on the north side of the range. Below this the laterals are much less distinct and are intersected by numerous erosion gullies. About four miles beyond the map, at an elevation of about 7,000 feet, the lower limit is found. For a distance of two and one half miles up the canyon from here one keeps crossing terminal moraines. The drainage has been so effectively obstructed that the stream above is almost as winding as the lower Mississippi. (See Plate X. taken from this canyon, above the inner terminal.)

In this canyon there existed a glacier 25 miles long with a maximum thickness of 2,000 feet.

Duchense Canyon.

From the Rock Creek to the Duchense, as from Lake Fork to Rock Creek, a number of small unglaciated canyons oc - cur. The Duchense is the most westerly large stream on the south side of the range flowing into the Green River . Across the divide to the west the drainage is into Great Salt Lake. The upper part of the Duchense lies in the once great snow field, as previously indicated. There is rather a greater development of till than in the canyons to the east. No typical cirque is found here because of the merging of so many basins into each other. Lakes are very numerous. The ice which found its way through this outlet seems to have been considerably less than that in the other canyons on the south side. The lower limit of the ice was just beyond the edge of the map, giving a glacier only about fifteen miles long. The principal ice drainage seems to have been into Rock Creek on the one hand and Provo on the other. Hades Canyon is the most southerly tributary which the ice occupied. Through this canyon there was connection with the Grandaddy Lake glacier.

Provo Canyon.

The Provo canyon forms the valley for the Provo River. It lies partly within the Hayden peak quadrangle and partly within the Coalville quadrangle. With respect to the Uinta Mountains, it forms the main canyon in the southwest part of the range. Its general direction is east and west, but about eight miles from its head it makes a rather sharp curve to the northward and continues in an almost due north and south direction the remainder of its course. Its length, from the town of Woodland which is located at the west end of the Uinta range, is about twenty four miles. The canyon has several tributaries, the most important of which are South Fork and Soapstone Creek on the south side, and North Fork and Boulder Creeks on the north side. The combined stream continues its way westward through the Wasatch range into Great Salt Lake, though the water is now largely utilized for agricultural and other purposes.

The canyon is a broad U-shaped valley, varying in width from about one half of a mile in the bottom at the head of Pine Valley to about two hundred yards five or six miles beyond. Above this it broadens out into an immense basin some three and a half miles in width by five miles in length. Just before the canyon begins to broaden out to form the basin, there occur two small water falls where the water drops down from shelf to shelf over the nearly

horizontal strata of quartzite which here constitute the bed rock.

The basin is very rolling, indeed hummocky expresses the idea better than any other word. Many of the depressions between the low rounded hills are filled with water the year round. These small lakes vary from a few rods to one half of a mile in diameter.

There is abundant evidence of glaciation in this canyon. The lower limit of the ice was at the head of Pine valley. Here the lateral moraines are, in places, still discernible on the slopes of the hills, but no distinct terminal remains.

From the end of the ice, the extra-glacial streams bore away large quantities of material which had been carried down by the ice. This material stretches down the river for some miles as a broad flat valley train which constitutes Pine valley. Boulders, pebbles, gravel, and sand, roughly assorted but getting gradually finer toward the lower limit are the constituents.

Just above the North Fork where the canyon makes a slight bend to the southward, are several small recessional moraines marking the halts in the recession of the ice tongue. The moranic material on the mountain sides becomes more prominent as one goes up the canyon. At the mouth of Soapstone Creek a lateral moraine reaches almost

to the top of the mountain on the south side of the canyon at an elevation of 9,000 feet and about 1,000 feet above the stream bed. On the north side of the canyon the evidence is not so plain, but from the height of the moraine on the south side the ice must have covered the entire mountain between the main canyon and the North Fork, except perhaps, one or two isolated peaks.

The probable explanation for so much material having lodged on the south side and very little on the north is that the direction of the ice movement was toward the south side. The bend which the canyon makes at the mouth of Soapstone, formed a sort of barrier in front of the advancing ice which , as a consequence,piled high up against the mountain on the south side and there deposited much of its material. This will be seen more clearly by referring to the accompanying maps.

Passing up the canyon the moranic material becomes less noticable and finally disappears entirely a short distance below the bend which the canyon makes to the north. At the bend the material again comes in and continues with increasing amount to the head of the basin.

The material of the moraines is quartzite boulders and rocks of various sizes, intermingled with finely ground detritus which constitutes the soil. The common size of the boulders is from one to two feet in diameter, though

some are larger.

The boulders of the drift in this canyon are not heavily striated although striations are not entirely wanting. Most of the stones are well worn and rounded. In the basin the bed rock is striated wherever exposed, the direction, as shown in the map, is in general parallel with the canyon.

As already stated, this canyon has a basin about three and one half by five miles in extent. It lies just on the south side of the crest line near the west end of the range. It is surrounded by a series of high peaks which, if continuous, would form a semi-circular belt; however, low passes separate the peaks and form passage ways from this basin into those of the Weber, Bear and the Duchense. The prominent peaks surrounding the basin, naming them from right to left, are Bald Mountain, 11,900 feet, Rieds Peak, about 11,800 feet, and Mt. Watson, 11,500 feet. Besides these there are some half dozen others over 11,000 feet high. Striations are found up to an elevation of 11000 feet, or 500 feet above the low cols which lead over into the other canyons.

Reference to the map will show that, with ice up to 11,000 feet and a considerable amount of névé above, nothing but the highest peaks remained uncovered. These stuck out as nunataks above the ice field. It will also be

seen that the ice of this basin was continuous with that of neighboring basins.

This basin, like that of the Duchense, contains a rather heavy deposit of till, the topography of which may be briefly described as one of pots and kettles. The depressions are mostly filled with water and form lakes, as already noted. From the top of Bald Mt. some seventy of these lakes were counted. The basins are usually round or approach that form. The hills may be either round or ridge like and when of the latter form are transverse to the direction of the canyon. In the soil of the drift timber grows profusely.

The canyon is broad and U-shaped with some till strewn over its bottom. No marked terminal occurs at the lower limit of the ice action. In this respect Provo canyon is somewhat peculiar. There is much glacial material strewn over the canyon as a valley train but no terminal moraine. Either the water issuing from the ice or subsequent floods must be responsible for the absence of the terminal moraine.

In the outwash train the present stream has cut a channel ten to fifteen feet deep which represents the amount of post-glacial work done.

South Fork. - South Fork of Provo gave rise to a small glacier about five and one half miles long which did not extend out into the main canyon.

Soapstone canyon. - Soapstone leaves the Provo six and one half miles above South Fork and heads somewhat west of south. Like the South Fork, it is a small tributary and far from the crest of the range. It was occupied by a small glacier which pushed out to join the Provo. Well defined lateral moraines are preserved. Two or three small lakes occupy moranic depressions in the head of the canyon.

North Fork. - North Fork is a left hand tributary about three miles down the canyon from Soapstone. It heads well back in the range and was occupied by a glacier which was continuous with that of the main Provo over the intervening divide.

Boulder Creek. - Boulder Creek, a tributary just below North Fork, heads seven miles back to the north east on the opposite side of the ridge from Smith and Morehouse canyon which is tributary to the Weber. Névé was continuous over the divide between the head waters of these two canyons. Ice pushed out through Boulder Creek into Provo canyon.

Beaver Creek.

Beaver Creek enters the mountains east of the town of Kamas and extends in a southwesterly direction a distance of seven miles when it swings round to the north and heads two and one half miles farther back at an elevation of 9,700 feet.

Its upper part, sometimes called Shingle Creek, gave birth to a small glacier as did also one or two small tributaries heading just to the north of the main canyon. None of these were of importance.

Hoyts Canyon.

This is a small canyon opposite the town of Marion about three and one half miles long and with a maximum elevation of 9,500 feet. It also gave rise to a small ice lobe which did not extend out to the valley.

PART II.

Discussion of General Questions.

Magnitude of glaciation.- From the references that will have already been made to the accompanying map it will have been seen that glaciation was somewhat extensive in the Uinta mountains. The crest of the range, especially on the south side, was practically one vast névé field with isolated peaks and long narrow ridges projecting, here and there, as nunataks, above the ice. The névé fields on the north side were more isolated but in several instances there was connection over ~~of~~ a low col with the névé on the south side of the range. The range could have been crossed from north to south or from east to west without putting foot upon bare soil. The extension of the ice north and south on an air line was about forty miles. King makes the statement that the maximum north and south extension was fifty miles *, but the writer thinks this too great and his estimates are based on accurate measurements on a good topographic map.

* King's Survey of the 40th. Parallel . Vol. I, p. 467.

Pre-glacial Work.

The question was raised, during the investigation of the region, as to whether the present canyons owe their development primarily to ice or water erosion. It is the opinion of the writer that the ice was simply a modifying agent of a pre-existing topography. This conclusion is based on the following facts; (1) there are many well developed canyons which were not occupied by the ice, the development of which certainly represents an amount of work far greater than that which has been accomplished since glacial times, (2) there are canyons which were not glaciated throughout their entire length, which show the characteristic V- form below the lower limit of ice, (3) of the canyons that were occupied by ice, none were filled to the brim, therefore that portion of these canyons above the upper limit of the ice was not produced by ice action. King says that " these V-forms either ante-date the glacial period or were produced by water issuing from the ice."* But what produced the 1,000 feet, more or less of these canyons above the ice line? There is no evidence whatever of ice action and the only possible conclusion is that water was the productive agent. Therefore since the part of the canyon below the limit of ice is the result of

* King's Survey of the 40th. Parallel. Vol. I.

water erosion and also that part of the glaciated portion of the canyon which is above the upper ice line, we can only conclude that the entire canyon was carved by running water, and that the ice has been but a modifying agent. Neither does King's statement seem to be a satisfactory explanation for the existence of those canyons which were not glaciated. Since these canyons did not reach far enough back into the range to participate in the ice drainage, it does not seem probable that they would have participated to any marked extent in the drainage of the waters which resulted from the melting of the ice.

In discussing the age of the canyons of the Sierra Nevadas, the Wasatch, and the Uintas as a whole King says, (Vol. I,p.478.) " That these canyons are not Tertiary is shown by the fact that in many places they cut through the basaltic lava flows which are clearly late Pliocene." He draws the conclusion, therefore, that these canyons are of Quaternary age and concludes by asking this question , "If these canyons, 3,000 to 4,000 feet deep, were only modified by the ice, what great flood period was there in the Quaternary prior to the glacial period by which they were produced?" This question is certainly an interesting one, the solving of which would be a great achievement. King suggests as an answer, (Vol. I, p. 787.) that since the Quaternary lakes show two flood periods in Pliocene

time separated by a period of dessication, these may correspond to two glacial periods. " It is possible", he says , "that the floods incident and subsequent to the first and greatest epoch produced the V-canyons and the second epoch modified these into the U-form," and concludes if this were the case all evidence of the first glacial epoch would have been obliterated by the second. It would thus seem that the question must remain forever unanswered.

If the above statement be correct, at the time of the first glacial epoch, the area was a vast plateau and therefore the ice must have covered every part of it, since there were no canyons through which the ice from the neve field might be discharged. We ought therefore to find some evidence of the first ice sheet on the present divides which, according to the assumption, were then part of an undissected plateau. Such evidence is entirely wanting and we therefore conclude that the present canyons existed and served as avenues of discharge for the first ice sheet.

The Quaternary age of the Uinta canyons cannot be regarded as absolutely proved by King's argument, since in these mountains there has been no volcanic action, but it is quite probable that the conditions which hold for the one place hold also for the other. Russell is of the opinion that the excavation of the large valleys of the Sierras began long before Quaternary times.* See Eighth Annual Report of the United States Geological Survey. Part I, p, 350.

Whatever be the age of the canyons and whatever the source of water, it seems reasonable beyond a doubt that the present canyons owe their development primarily to aqueous erosion, and are therefore pre-glacial so far as our knowledge will permit us to determine.

Glacial Work.

If the preceding conclusion regarding pre-glacial work be tenable, then the glacial work simply modified the features already existing. A correct measure of glacial erosion would mean the restoration of the canyon to its original V-shaped form and then an estimate of the amount of material removed to produce the present form. This, how ever, would be an almost hopeless task. We might calcu - late the cubic contents of the excavated gorge, as Russel has done, and see how the amount of material represented in the moraines and valley trains corresponds with that re- moved from the canyon. This involves many inaccuracies arising from irregularities in the canyon and from our in- ability to calculate the amount of material removed by the ice which has been carried beyond our observation. More from curiosity than hope of accuracy one calculation will be made.

An estimate on Rock Creek canyon gives the following results: length of canyon twenty five miles, average depth, one third mile, average width one and nine tenths miles. The cubic contents of the gorge from the above data is 15.8 miles. In order to reconstruct the pre-glacial shape of the canyon and thus obtain the amount of material re- moved prior to the ice invasion, it is necessary to take

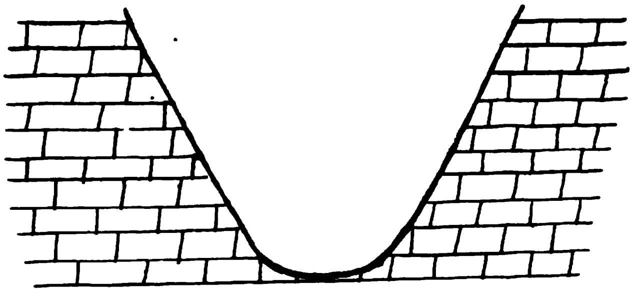


Fig. 6.

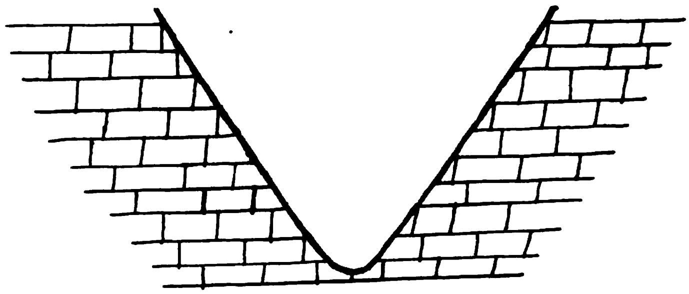


Fig. 7.

Figure 6.- A cross section of Rock Creek canyon as it is today.

Figure 7.- An attempted restoration of the same canyon in preglacial times.

A comparison of the two shows the amount of work done by the ice.

some large canyon which has not been glaciated or which has not been glaciated throughout its entire length, and make measurements of the average width of the bottom of such a canyon. The most favorable canyon for such measure ments is the Weber below the limit of ice action. Meas - urements on this canyon give an average width at the bottom of 0.18 miles. Supposing the average width of the bottom of the Rock Creek to have been about the same before glacial times as that of the present unglaciated part of the Weber, we get an average width for the entire canyon of 1.6 miles as compared with 1.9.miles for the present canyon. The cubic contents of the preglacial canyon on this basis is 14.6 cubic miles. The difference in volume between the pre- and post-glacial gorge is 1.2 cubic miles which according to our estimate represents the amount of material removed from the canyon by the action of the ice. While the error in this estimate may be considerable, yet it serves the purpose for which it was intended, that is to show the insignificance of glacial as compared with preglacial work. Figures 6 and 7 are drawn to scale to represent the shape of the present and pre-glacial gorge of Rock Creek.

However the work done by the ice has not been altogether insignificant. Most writers agree that cirques have been formed by ice. Their entire absence in unglaciated

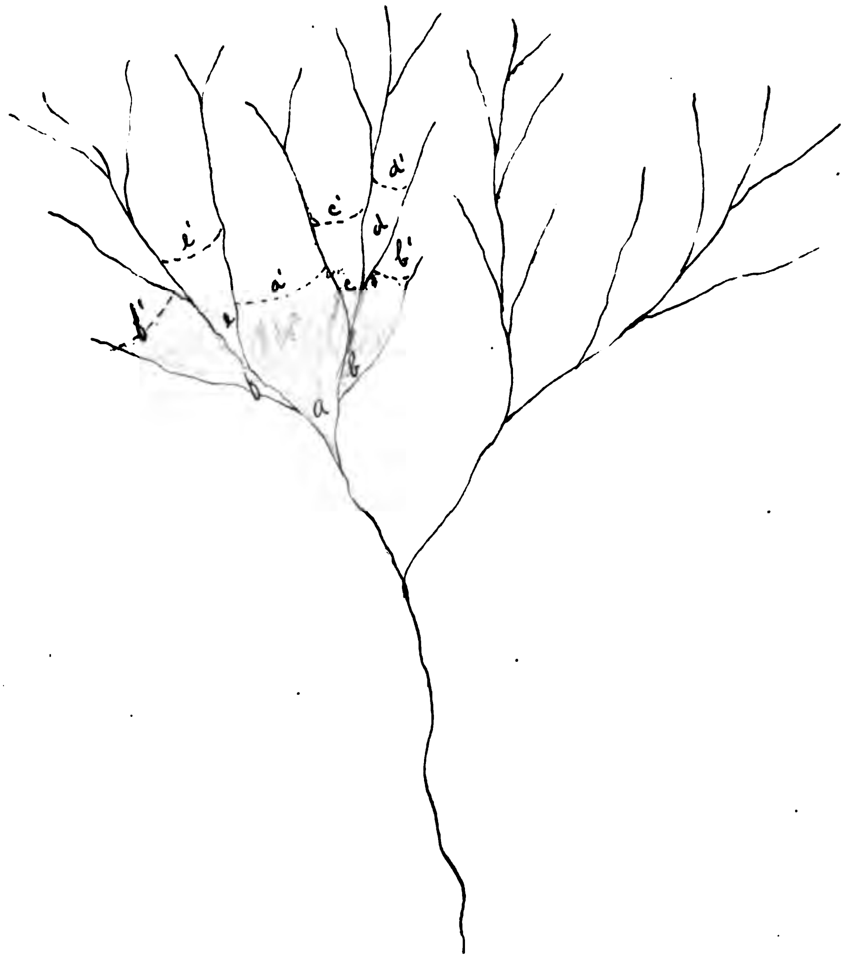


Figure 16.- Ideal figure showing the manner in which several head tributaries of a mountain stream may be made to coalesce by the action of the ice to form one large cirque.

regions should put the question forever beyond the realm of dispute. The writer is of the opinion that here the greatest work of the ice is accomplished. In the comparatively straight canyons, as soon as minor irregularities are trimmed off and the bottom of the canyon hollowed somewhat to fit the ice surface, erosion progresses very slowly. As Professor Salisbury tersely puts it, " Ice cannot take hold unless it has a handle to take hold of." In the head there are more handles than lower down in its course. Everyone who is at all familiar with mountain canyons, knows that near their heads they divide and subdivide into a great number of small ravines which spread out fan-shaped with the open part up stream. In other words we have the outline of a cirque. This is illustrated in the accompanying Figure86, which is intentionally exaggerated.

An examination of a topographic map of any youthful region will confirm this statement. Between these ravines the divides are comparatively low. The~~re~~ir basal width is an inverse ~~fraction~~ function of the number of streams. When snow accumulates in these places in sufficient quantity to form a glacier, there are at first many avenues of discharge for the moving ice. These ice rills unite to form creeks, streams and rivers just as the water rills do. Every projecting nose forms a handle of which the ice can take hold. As these noses are cut back by the constant grinding of the

ice our small ravines begin to merge into each other to form basins and basins finally merge to form cirques. For example; suppose that point a has receded to a', indicated by the dotted line, during the same time b will have receded to b', c to c' , d to d', e to e', and so on. We see that the only requirement is time and all the smaller basins will have merged into one.

One of the best illustrations of this principle in the region under consideration is furnished by Lake Fork. In basin 50 there was evidently, at one time, a projecting nose between the two streams almost all traces of which have been removed. Between 50 and 51 the nose has only been partially removed, between 51 and 52, more completely. Between 52 and 53, 53 and 54, etc., prominent ridges still remain. A little more time is all that was needed to make the whole one complete ideal amphitheater.

To illustrate the opposite case, a canyon in which practically no cirque was formed, take the East Fork of Bear River. Here we have simply a straight chute from head to mouth. So far as structure, material, amount of ice, etc. are concerned the conditions are just as favorable for the development of a cirque here as in Black Fork to the east. The only apparent reason why no extensive cirque was formed is the absence of tributaries at the head of the canyon. Had the glacial period lasted long enough

to have removed the ridge between the two large forks, a typical cirque would have been formed.

It is not the idea, however, that this process alone forms any cirque. There is grinding at the bottom, grinding at the sides, sapping along the " bergschrund", and probably other factors, all of which co-operate in removing intervening ridges and in enlarging the periphery, until we have produced those shrines of mountain grandeur for which glaciated canyons are notable.

The writer was struck with the idea here presented in reading the writings of Russell, Matthes, and others on the origin of cirques and it seemed to him that they had omitted one important factor co-operating in the problem.

Post-glacial Work.

A discussion of post-glacial work resolves itself into work done by running water, and work done by the forces of weathering.

The first can be disposed of readily. Work done by streams since glacial time is very trivial. In no case has a channel of any conspicuous depth been cut in solid rock. There are some instances where streams have cut twenty to forty feet through terminal moraines but even these are not numerous.

The amount of work done by frost and ice is more conspicuous. Every cliff face has an immense accumulation of talus at its base. Whole mountain peaks are in such a stage of decay that in climbing one you seem to be walking over a heap of large angular blocks. Only where the slope is too great for such blocks to lodge are the solid ledges exposed.

Glaciation

on North and South Sides of Range Compared.

It was anticipated before going into the region that we would find the heaviest glaciation on the northern slope. That the opposite is the case is shown by the following facts,(1) the lower limit of ice on the north side is about 8,000 feet, on the south side,less than 7,000 feet; (2) the length of the glaciers on the south side averages about five miles greater than on the north; (3) the thickness of the ice was greater for the south side.

The factors which enter into the problem are : (1) Temperature,(2) precipitation,(3) direction of prevailing winds, (4) size of névé field, (5) length of canyon.

So far as temperature is effective, the north side of the range is most favorably located for extensive glaciers, for here the snow field is less exposed to the sun's rays. So far as precipitation is concerned, if the conditions were the same in Pleistocene times as now, it would be at a maximum on the south side of the range. At present the moisture bearing winds come from the southwest, they therefore strike the south side of the range first and lose much of their moisture in passing over. But this very direction of the winds tends in another way to increase the amount of snow on the north and east sides of the mountain peaks,

by blowing loose snow over to the north side. This factor however is one of minor importance. The collecting area or névé field is much larger on the south side of the range. This factor is, therefore, favorable for the production of the largest glacier on the south side. The reason for the greater collecting area on the south side lies in the fact that the axis of uplift was much nearer the north face of the range. The strata therefore, on this side are steeply inclined and descend quickly to the plains, while on the south side the gentle inclination of the strata carries them to a much farther distance before the plains are reached. This brings in the next factor, the length of the canyon, which is greatest on the south side. As a consequence the ice would travel farther before reaching the lower plains where melting balanced movement. The glaciers were therefore longer.

Three of the controlling factors, viz., the greater collecting area, the greater precipitation, and the greater length of the canyons, fall together on the south side of the range. The other two, viz., lower temperature and drifting effect of the prevailing winds favor the production of the largest glaciers on the north side. Since the most extensive glaciation did occur on the south side of the range we must conclude that the temperature and prevailing wind factors were subordinate to the greater col-

lecting areas, greater precipitation, and the greater length of canyons.

The more gently inclined strata, the greater abundance of ice, and the immense size of the basins, it is believed are responsible for the greater development of lakes on the south than on the north side of the range. When the ice cuts the strata at a small angle there is more opportunity for forming rock basins than where the beds are cut at a very high angle. The more vigorous the erosion, the more heavily loaded the ice, and hence the greater amount of till that is likely to be left when the ice disappears. This gives opportunity for greater inequalities and hence for the production of moranic lakes. The conditions on the south side of the range were, therefore, more favorable for the production of lakes, both moranic and in rock basins, than on the north side, and the number of the lakes is correspondingly greater.

Epochs.

The evidences set forth in the previous discussion which have an important bearing on the question of epochs, are, (1) the deposition of the terminal moraine in Weber canyon opposite the mouth of Smith and Morehouse canyon by the ice of the latter, (2) the talus moraine in No. 73 of Weber, (3) the inner set of terminal moraines and the valley trains extending from them, discussed in detail in connection with the Bear River canyon, but occurring in several other canyons as well, (4) the push moraine in Middle Fork of Blacks Fork. These evidences will be summarized here and in addition there will be given the evi - dence furnished by the Quaternary lakes of the Great Basin, evidence furnished by the Wasatch Mountains and also by the Sierra Nevadas.

In discussing the terminal moraine at the mouth of Smith and Morehouse canyon, it was shown that the moraine (See figure 1) could not have been deposited while the Weber glacier extended outtor beyond that point. The moraine must, therefore, have been deposited after the Weber glacier had retreated farther up the canyon. It was shown that the only possible ways in which the moraine could have been formed are, (1) that the ice in the Weber may have receded faster than that in the Smith and Morehouse canyon

and that as a consequence, when the Weber glacier had retreated beyond Smith and Morehouse canyon, the glacier of the latter, being no longer obstructed, might have moved out into the Weber in the position marked by the terminal moraine, indicated by the red line in the figure; (2) that the ice in the two canyons may have receded at an equal rate and the moraine have been formed by a second advance of ice in which the Weber glacier did not extend far enough down the canyon to interfere with the Smith and Morehouse glacier.

In discussing the first possibility it was stated that there are certain factors to be considered which would influence the relative rates of recession of the two glaciers These factors are, (1) the comparative size of each nèvè field, (2) the comparative distance of each nèvè field from the moraine A.C.D., (3) the comparative gradients of the two canyons and the consequent comparative velocity of ice movement in each, and (4) the comparative altitudes of the two nèvè fields.

It was shown that the comparative gradients of the two canyons are as $1 : 1\frac{1}{3}$ in favor of Smith and Morehouse canyon, that is the gradient per mile is one third greater in Smith and Morehouse canyon than in the Weber. A comparison of the distance of each nèvè field from A.C.D. showed a ratio of $1 : 1\frac{1}{2}$ in favor of the same canyon,

that is the Smith and Morehouse nevè field was one half nearer the moraine than the Weber nèvè field. Both of these factors are favorable to the first possibility, that is, that the ice from Smith and Morehouse was able to maintain its terminus at the mouth of its canyon after the Weber glacier had retreated farther up the canyon, and that being freed from obstruction the Smith and Morehouse glacier pushed out into the position A.C.D. and built the moraine, whereas it had previously been deflected down stream by the Weber glacier.

On considering the other two factors; viz.,the comparative size and altitude of the nèvè fields for each glacier it was found that the balance was on the other side, that the combined nèvè fields of the Weber were probably twice as large as that of Smith and Morehouse, also that the average altitude of the former was at least 200 feet higher than that of the latter. These factors, because of the increased precipitation and increased accumulation of snow, would have produced a very much larger and more vigorous glacier in the Weber. It seems quite probable that the increased <u>size</u> of the Weber glacier more than compensated for the increased <u>velocity</u> and shorter <u>distance</u> of the Smith and Morehouse glacier, and therefore that the latter glacier receded as fast or faster than the former and consequently did not build up the moraine A.C.D. during its

retreat.

The effect of the increased size of the névé field on the size and length of the glacier is well illustrated by a comparison of the Rock Creek and Duchense glaciers. In these two canyons the gradient is practically the same and the altitude common. The size of the Rock Creek névé field including its tributary, Brown Duck Lake, was to the size of the Duchense névé field as $2\frac{1}{6}$: 1. The length of the Rock Creek glacier is twenty five miles, that of the Duchense fifteen miles , or a ratio of $1\frac{2}{3}$: 1. Stated in another way, the Rock Creek névé field,with an area of a little more than twice that of the Duchense,supported a glacier one and two thirds times as long. From this comparison we see what an important factor the size of the névé field is in determining the length of the glacier. We therefore return with greater confidence to the supposition that the Weber névé field with an area about twice that of Smith and Morehouse could easily have supported a glacier one and one third times as long, notwithstanding the increased gradient of Smith and Morehouse canyon.

The only conclusion left, therefore, is that the moraine A.C.D. was built by a second advance of the Smith and Morehouse glacier, and that the reason that the Weber glacier did not interfere with it in this second advance was that the ice from two of the Weber tributaries, 70 and 73, did

not unite with the glacier which moved down the main canyon, as a result of which the neve field which fed the glacier of the Weber was much decreased in size and the glacier correspondingly weaker. It is believed that this second advance of ice represents a second epoch.

In discussing the Bear River canyon, it was shown that a very conspicuous feature of this as well as several other canyons, is an inner set of terminal moraines in just about the same position in each fork and situated just above the junction of the several forks to form the main canyon. From these moraines outwash plains invariably proceed. Occasionally in these outwash plains, especially near their outer margin, one finds small mounds rising above the otherwise level plain. These mounds appear to be the tops of small hills which have been partly buried by the outwash train.

The mounds themselves are of glacial origin. The conclusion drawn is that prior to the outwash of the valley trains, and therefore prior to the formation of the terminal moraines from which they proceed, that part of the canyon now occupied by the valley train was occupied by till with an undulating topography; that with the outwash of the valley train this undulatory topography was largely obliterated, partly by a filling up of the depressions and partly by a cutting down of the swells, but that some

of the swells, principally those near the outer margin of the waters which formed the outwash plain, were not cut down, neither were they completely buried. In addition to the partly buried mounds of till there is sometimes found a relation of valley train and lateral moraine which indicates a lapping of the valley train over the lower part of the moraine. Instances of this kind are better shown in Blacks Fork than in the Bear River canyon. The terminal moraines which mark the maximum extension of the ice are almost always less in tact than the inner set of terminals from which the valley trains proceed, a fact which suggests at once the greater age of the former.

To account for the facts given above, one of two things must have occurred; (1) during the retreat of the ice it must have halted for a very long time at the position occupied by the inner terminals, or (2) after the retreat of the first ice sheet there must have been a second advance and this inner set of terminals marks the maximum extension of that advance. It then becomes a question as to which of these two possibilities best explain the facts. So far as the relations of the valley trains to the partly buried mounds and to the lateral moraines formed by the maximum extension of the ice, between which the valley trains extend, are concerned either of the above cases will apply equally well. Whether the ice stood at the inner set of terminals for a

long time during the general retreat of a first ice sheet, or whether it stood there for the same period of time during a second advance the facts would remain the same. There would have been water issuing from the end of the glacier which would flood the canyon below carrying with it much of the material that was being dropped at the end of the ice. As this material was deposited lower down the canyon it would fill up the depressions and cover or partly cover the swells in the ground moraine left by the retreating ice, and thus in either case we might find some partially buried mounds. In the same way, where the material was deposited in contact with a lateral moraine, the former would lap up over the latter. Along these two lines then, no inference can be drawn either one way or the other - the ice might have been retreating or it might have been at the position of maximum advancement.

When the time element is considered in connection with the two possibilities given above, there is little more evidence for drawing conclusions either one way or the other than in the cases discussed above. If there be any preponderating evidence in either direction it seems to me that that evidence is in favor of a second advance of the ice. If the inner set of terminal moraines were formed by a halt of the retreating ice of a first advance that halt must have been a very prolonged one. Indeed, it must have

been longer than all the other halts above and below these terminals combined. I am perfectly safe in saying that the material represented in these inner terminals and the outwash from them is much greater than that represented in all the other terminals combined, the one of maximum ex - tension excepted. Between these inner terminals and the outer ones evidence of halts in the retreating ice sheet are very meager, and when present, they indicate only a brief stay in the general retreat. Above the inner set of terminals, the evidences of halting in the retreat of the ice are more numerous, but they invariably point to a very brief one as compared with that represented by the inner set of terminals. Why should the halt of the receding ice sheet be so much greater at this point than at any other place where a halt was made, or than all the others combined? The only answer is that the melting of the ice was balanced by the downward movement for a greater length of time. In other words the conditions which maintained while the ice was at its maximum extension were repeated, though for a somewhat less length of time. It seems more rational to the writer to attribute the repitition of these conditions to the coming on of a second glacial climate after the disappearance of the first rather than to a rejuvenation of the adolescent condition of the latter.

Concerning the apparent age of the outer and inner set of terminal moraines, the latter certainly appear the more recent. As already stated, they are undissected by erosion and with the exception of the narrow channel cut out by the canyon stream, are apparently in an undisturbed condition.

From the above argument it is seen, that in so far as there is any preponderating evidence in favor of one of the two possible explanations, that is that the inner set of moraines was formed by a halt in the retreat of the first ice sheet or by the advance of a second, that evidence is in favor of a second ice advance and therefore two ice epochs. But it is admitted that the evidence is not conclusive.

We next turn to a consideration of the push moraine in in Middle Fork of Blacks Fork. It was pointed out that in this canyon at about one third the distance from mouth to head a very characteristic terminal moraine occurs. This moraine is composed of large angular masses of rock twenty and thirty feet square, with others that are smaller, which have not been rounded, polished, or striated by the ice. There is practically no fine detrital material mixed with the boulders. The source of the boulders of the moraine is a limestone cliff on the east side of the canyon, less than a quarter of a mile away. This cliff is the only source of limestone in the canyon above the moraine.

With regard to the stage of ice movement in which this moraine was formed, there are but three possible assump - tions:- (1) that it was formed by the first advance of the ice, (2) that it was formed by the retreat of the first ice sheet during one of its halting periods, (3) that it was formed by a second advance of the ice subsequent to the retreat of the first advance. Each of these three possibilities will be considered in order.

1. That the moraine was formed by the first advance of the ice. - We know that during its first advance, the ice moved at least two and one half miles farther down the canyon to its junction with the main fork and there remained sufficiently long to build up a terminal moraine many times larger than the one under consideration. Further, it is very probable, indeed almost certain, that the ice in its first advance did not stop at the position now marked by the moraine at the mouth of the canyon, but on the contrary united with the ice in the main canyon down which it moved several miles. If this moraine had been formed by the advance of the first glacier, it would have been destroyed by the further advance of the ice which built it. Therefore, since the moraine in question does not occur at the maximum extension of the first ice advance, it could not have been built and preserved as it is by that advance.

With regard to the second possibility; viz., that the

moraine was formed by the retreat of the first ice sheet during one of its halting periods, let us consider,(1) the effect of the <u>advance</u> if the ice on the <u>talus</u> at the foot of the limestone cliff from which the material for the moraine in question was derived, (2) the effect of the ice on the <u>cliff</u> itself.

(1) The effect of the advance of the ice on the accumulated talus. During the unknown ages that elapsed between the erosion of the canyon and its occupancy by the first ice sheet a great amount of talus would have accumulated at the base of the cliff in question. This talus was in the direct path of the advancing ice and was in no condition to maintain its position before so great a force, Therefore when the ice encountered the talus pile, the latter must have been borne away by the former, either before it or beneath it or both. It is not the idea that the loose material was all picked up at once by the ice as a handful of pebbles by a school boy, but there seems no escape, in the mind of the writer, from the supposition,that long before the ice had begun to retreat from the position of maximum extension as outlined above, all loose material in the bed of the canyon would have been carried away and the ice would have been working on the bare rock floor. That being the case, so far as the talus is involved in the story, there would have been none at hand out of which the moraine might have been formed by the retreating ice. But if we

admit for sake of argument that some of the talus might have remained near where the ice found it and thus have been available at the retreat of the ice, we cannot conceive that it would not have been highly glaciated by the quartzite material from the head of the canyon contained in the over-riding ice mass. But the rock masses in the moraine show no striations or polishings, hence we are forced to conclude that the moraine was not formed by retreating ice from talus material accumulated at the base of the cliff.

(2) Let us now consider the effect of the advancing ice on the cliff itself. When the ice first advanced it would find the cliff in the most favorable condition for attack. Joints and fractures would have cut its face into blocks of various sizes and there would probably have been numerous overhanging masses, the counterparts of their fellows in the canyon below. These blocks would have been easily rent from the cliff by the advancing ice and because of this very ease of dislodgement would be removed during the earliest stage of the ice invasion. As the action of the ice on the cliff continued the readily available material would continually decrease, the irregularities of outline of the cliff face would constantly diminish until finally the only source of large blocks would be that part of the cliff which projected above the ice, and which would still have been exposed to the ordinary forces of weathering.

But a reference to the map will show that the portion of the cliff above the ice was small and hence would not yield a very large amount of material. Therefore in a very early stage in the glacial history the amount of large angular blocks available would be very small. On the other hand, the proportion of fine detrital material carried by the ice would increase, at least up to a certain limit, directly as the length of ice action.

The only possible conclusion is, therefore, that a moraine built up by retreating ice would have consisted of boulders almost universally rounded, more or less, and ice-worn, mixed with a considerable amount of fine detritus. The boulders of the moraine in question are not ice worn or striated and with them there is practically no fine material, hence the moraine could not have been formed by retreating ice. Since the first two possibilities cannot be used to explain the existence of this particular moraine, the third and only other possible explanation might be considered as established. We will see how the facts fit the case.

The third hypothesis is that the moraine was formed by a second advance of the ice after a period of absence of ice and normal weathering, sufficiently long to admit of the accumulation of a fresh mass of talus at the base of the cliff, and the consequent re-establishment of a jointed

and fractured irregular cliff face. We saw that in considering the first hypothesis, that the only objection against it was the fact that the moraine did not correspond to the position of maximum ice extension. After the retreat of the first ice sheet, the cliff would have been exposed again to the normal forces of weathering which would manifest themselves in the same manner as before the first ice epoch, viz., in the accumulation of talus at the base of the cliff and the development of joints, fractures and irregularities in the cliff face.

With a long, arid, interglacial period in this mountain region the forces of weathering would have been able to do a great amount of work, and therefore great talus piles would have accumulated again at the base of prominent cliffs. A practical illustration of this fact is found in the great talus piles at the bases of all prominent cliffs in the region today, which certainly have accumulated since the last disappearance of the ice. With this talus material and the blocks broken from the face of the cliff by the ice itself, an advancing ice sheet could form a terminal moraine of angular blocks with little detrital material, provided it did not move far beyond the place where the talus had accumulated, thus destroying more or less the angularity of the rock masses and increasing the amount of detrital material.

Since the moraine in question is undoubtedly a terminal moraine, since it is composed of angular blocks, unglaciated and with little or no fine material, since it could not have been formed by the first advance of the ice sheet which extended much farther down the canyon, since the nature of the material unquestionably forbids that it was formed by a retreating ice sheet, and since the moraine could have been formed by a second advance of the ice after a long period of weathering and accumulation of talus, we must conclude that the moraine was formed by such a second advance of the ice after a long interglacial period, during which the processes of weathering were active, and the interglacial period was sufficiently long to admit of the accumulation, at the base of the cliff, of the talus of which the moraine was composed. In other words, this moraine is conclusive evidence of two glacial epochs separated by a period of ice absence.

Similar evidence of two ice epochs is furnished by the talus moraine below Fish Lake in No. 73 of Weber, but the evidence is less conclusive than in this case and cannot therefore be used to such good advantage.

The above facts present a fairly strong case for the support of two ice epochs in the Uintas. Evidences furnished by the Quaternary lakes of the Great Basin, by the Sierra Nevada and Wasatch mountains will now be given.

The following argument is taken from the writings of Gilbert and King in their discussion of the relation of the Quaternary lakes of the Great Basin. It has been assumed from pure analogy that the history of these lakes, Bonneville and Lahontan, is synchronous with the glacial history of the region. It has been shown that there were two flood periods for the lakes separated by a period of drought and dessication. It has also been shown that the last flood period was but yesterday in a geological sense. The recency of the ice invasion has been abundantly attested. It has been shown that the same climatic changes which filled the mountains with ice were competent to fill the lakes with water. It has therefore been argued by many that the two events were synchronous.

Two lines of evidence, based on facts rather than inference will be considered here.

1. The Evidence from Molluscan Life.* A collection of recent mollusca from Bonneville and Lahontan areas showed that of 33 species, 26 are identical with the Pleistocene species, that is, about five sixths of the species of Pleistocene and recent mollusca are similar. The dissimilarity of the remaining one sixth may be due to the incompleteness of our knowledge of Pleistocene life. It is therefore assumed that Pleistocene and recent fauna of the Bonneville-

* Monograph I. United States Geological Survey. pp. 297-302.

Lahontan area are identical. The fossil shells of the 26 identical species are smaller than the living shells of the same species. This "depauperation" may be due to a colder climate or to an increased salinity of the waters. Without entering into a detailed discussion of the experiments of Mr. Call as given by Gilbert, we will give his results.

Careful measurements were made of shells of mollusca now living in waters of varying temperatures and also of shells from waters of varying degrees of salinity. These experiments showed almost exactly the same ratios of depauperation (about 100 : 87) from the effects of cold and salinity. But since in its last flood period. Bonneville had an outlet and was therefore a fresh water lake, and since shells taken from sediments deposited while the waters were fresh show the same depauperation, Gilbert concludes that the depauperation is due to cold and that the last flood period was a cold period, therefore it was coincident with the glacial epoch. A similar inference cannot be made for the first flood period, since at that time the lake had no outlet and its waters, therefore, were salt.

2. Evidence shown by chemical precipitates. * The lacustrine deposits of Lahontan up to within 500 feet of its upper limit contain thinolite (a tufa deposit of Ca CO_3) deposits which have been proven to be pseudomorphs of calcium

* King's Survey of the 40th. Parallel , Vol. I.

carbonate after gaylussite ($Ca\ CO_3 Na_2 CO_3 + 5\ H_2O$). A study of present lakes shows that at the time of greatest dilu - tion (the flood periods) gaylussite crystals are dissolved, and redeposited when the waters become more concentrated by evaporation.

The absence of gaylussite in the upper 500 feet of Lahontan deposits shows that at flood time the water was of sufficient dilution to hold the alkaline carbonates in solution. Concentration and saturation with alkaline carbonate is therefore necessary for the deposition of gaylussite. This concentration and deposition occurred as a result of dessication during the inter-flood periods. For the re - placement of the alkalies by calcium, lime must have been brought into the lake in solution by streams. The present dessicated remnants of Lahontan are so fresh as to permit the healthy living of fresh water fishes. They do not de- posit either gaylussite or thinolite. These remnants therefore must be much more dilute in saline constituents than the much more extended Quaternary lakes. In order to bring about this dilution there must have been a sluicing out of the former lake. This sluicing out was accomplished by the floods incident to the second glacial epoch.

" The history of the lake as shown by these thinolite deposits is, (1) a long period with no outlet during which the waters were concentrated by evaporation, (2) the deposition of gaylussite, (3) a second flood period which

raised the level of the lake to the point of overflow and washed out the saline contents, (4) either a cessation of saline carbonates from springs or an increase in the amount of calcium carbonate in the streams, resulting in a replacement of the gaylussite by thinolite before the waters were sufficiently dilute to take the gaylussite into solution, (5) the flood period with outlet continued long enough to remove most of the saline products. The chemical history of Lahontan, which corresponds with the sedimentary history of Bonneville, is directly correlated with the glacial e - pochs, the first flood plain corresponding with the first glacial epoch and the second to the Reindeer epoch."

How much weight to attach to this argument can be judged from the fact that Gilbert maintains that Lahontan had no outlet. *

Evidence from the Sierra Nevadas.-

Professor Russell shows conclusively that in the Sierra Nevadas there were, not only two, but three advances of the ice separated by periods of warmth, during which the ice retreated far up the canyons if it did not entirely disappear. This evidence consists in the fact that in Bloody and Parker canyons the ice, on emerging onto the plain was

* Monograph I. United States Geological Survey. p. 301.

in each case deflected from its previous course over-riding its former path. *

Evidence from the Wasatch.- The most conclusive evidence bearing on epochs comes from the Wasatch and was discovered by Mr. Atwood during the summer of 1901. The results of his work have not yet been published and will be but mentioned here. In one of the canyons of the Wasatch Mr. Atwood found two deposits of till separated by an old soil line. This is the only case of the kind yet known but seems conclusive.

A party under the direction of Professor Salisbury last summer is said to have found conclusive evidence of two e - pochs in the Bighorn Mountains. What the evidence is the writer does not as yet know.

Putting all the above facts together the argument for two glacial epochs in the Cordilleras is much strengthened. If it be proved that there were two glacial epochs for the Sierra Nevadas to the west and for the Big Horns to the east of the Uintas, and more especially for the Wasatch almost adjacent to them, it is reasonably safe to say that there were also two ice epochs in the Uintas.

* Eighth Annual Report of the U.S.G.S. Part I. pp. 338-341.

Economic Features.

Numerous reservoir sites have been formed by the terminal moraines which cross various of the canyons. Two good illustrations are afforded by the moraines in Smith and Morehouse canyon and Stillwater Fork of Bear River. Some surveying is being done upon these sites but is as yet rather limited.

Besides reservoir sites, natural reservoirs have been formed in the numerous lakes which store up the water in the spring and dole it out during the dry summer months.

The soil formed by the ice is an excellent producer of timber. In such basins as Mill Creek, Grandaddy Lake, and Brown Duck Lake, timber grows with a luxuriance and profusion that is in strong contrast with canyons like Black Fork.

Recency of the Glacial Period.

Striations and polishings, even in their minutest detail are well preserved. Debris rests where it fell, lakes are undrained, and moraines free from dissection. Even the soluble limestones of the drift are not disintegrated. As elsewhere pointed out the huge limestone blocks of the terminal moraine of Middle Fork of Blacks Fork show little more disintegration than talus blocks now accumulating at the base of the cliffs. All of these evidences point to the comparative recency of the glacial epoch in the Uinta Mountains.

SUMMARY.

In the foregoing discussion it has been shown that during Pleistocene times the Uinta Mountains comprised a region of extensive Alpine glaciers. Quoting again the words of King, "The Uintas were comparable to the Alps but far more grand". The minimum altitude reached by the ice was less than 7,000 feet. The longest glacier was between 25 and 30 miles in length, while the maximum thickness of the ice was some - thing like 2,000 feet.

As a result of this glaciation beautiful amphitheater - like cirques have been developed at the head of all the large canyons. In these basins the marks of glaciation are as fresh as if the ice had disappeared but yesterday. The bed rock is smoothed, polished, and striated in a beautiful manner. In addition every cirque is studded with lakelets of clear cold water, some of which occupy depressions carved out of the hard rock floor, while others are enclosed by moraines. Lateral moraines occur on the mountain sides at elevations varying from 1,000 to 1,800 feet above the present streams.

The canyons themselves have a broad,open U-shaped form from mouth to head. It has been shown (pp. 75-80) that the development of these canyons is due primarily to preglacial erosion and that the ice has been but a modifying factor. It has been further shown, that while the ice did considerable

work in cleaning out and widening the bottoms of the canyons, the principal work accomplished was the development of the cirques. These, it is believed, are strictly due to ice action. (See pp.80-83)

Although the south side of the range is exposed more directly to the sun's rays, the glaciation was most extensive on that side. This is due to the following factors, (1) the prevailing winds are from the southwest, therefore precipitation was greatest on the south side, (2) the collecting area for snow was much greater on the south side, (3) the greater length of the canyons on the south side required that the ice travel farther before reaching the level where melting exceeded downward movement.

Correlative with the more vigorous glaciation we have a much more pronounced development of lakes on the south side of the range.

In discussing the question of glacial epochs (pp. 88-102) in the light of facts observed it has been shown that, while the evidence is not conclusive, it points strongly toward the existence of two separate ice epochs in the Uintas, as has been the case in the Wasatch, the Big Horns, and probably in the Sierra Nevadas. The history of the Quaternary lakes, Bonneville and Lahontan, also point to the same conclusion.

The perfect preservation of the striae, the undrained condition of the lakes, and the almost complete absence of weathering in the drift all point to the comparative recency

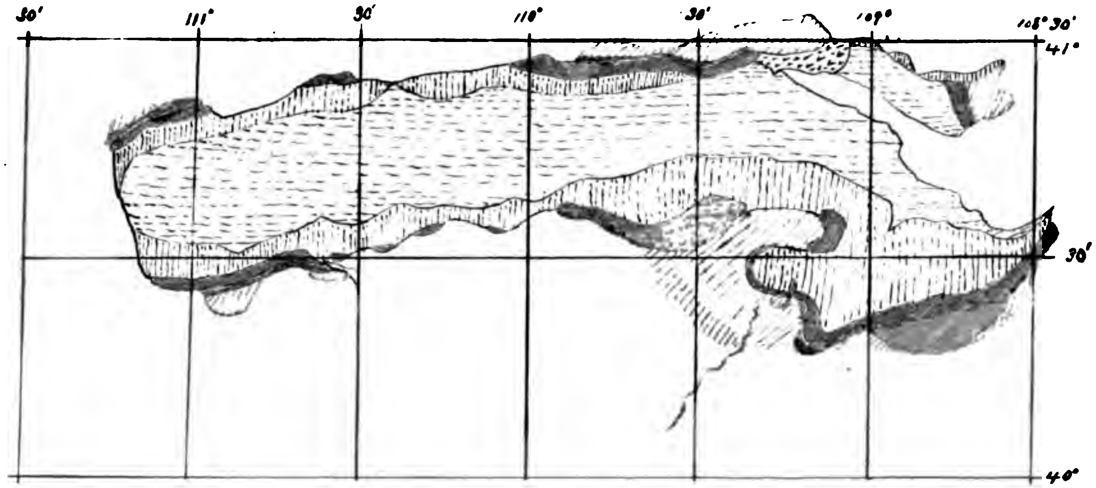
of the final disappearance of the ice. Prof. Salisbury thinks that the Wasatch till corresponds to the Wisconsin till of the interior. Thus in the West as in the East , the Pleistocene period was characterized by a glacial climate.

In conclusion, the history of the range briefly summarized is as follows. The orographic disturbances which closed the Cretaceous resulted in the uplift of a broad plateau-like area with the strata dipping very gently to the south and a great fault and steep dip to the north. Between the inauguration of this uplift and Pleistocene times, the forces of normal weathering and disintegration had succeeded in carving the plateau into a great system of deep canyon gorges and serrated mountain peaks. As the Pleistocene period came on the climate grew colder and precipitation probably increased until finally glacial conditions prevailed and the region became one great snow and ice field. Finally the climate again moderated, glacial conditions disappeared. This was followed by a period of aridity and dessication of the inland lakes. After the lapse of a period sufficiently long to admit of considerable weathering and disintegration, glacial conditions returned but on a less extensive scale than in the previous glacial epoch. Since the disappearance of the last ice sheet aridity has prevailed but the time has been so brief, geologically, that little has been added to the history of the region.

PLATE I.

Geological map of the principal part of the Uinta range. Taken from King's Survey of the 40th. Parallel.

Plate I.



Geologic map of Uinta Mts. After King.

Scale, 30 mi. = one inch.

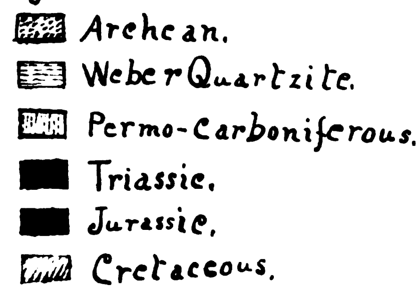


PLATE II.

A typical U-shaped canyon as found on the north side of the Uinta range, incidentally showing the position of the lateral moraines on the right-hand side.

Plate II.

PLATE III.

A typical glaciated cirque showing polished and striated rock surface and rock basin lakes taken from the south side of the range. The horizontal position of the strata is well shown, also the accumulation of talus at the base of the cliffs.

The observer is looking down the canyon.

Plate III.

PLATE IV.

Another glaciated cirque showing somewhat of a rôches montonnées topography, the features of PL. II, and also the sudden drop off down to the stream bed giving the ' Box~~er~~ canyon ' characteristic of the south side of the range.

Plate IV.

PLATE V.

The especial feature shown is the lateral moraine from the main canyon completely damming up the mouth of the tributary canyon on the left. The tributary is also glaciated. The U-shape of the canyon is again shown and away to the left the snow banks still lingering on the high peaks.

Plate V.

PLATE VI.

View of a rather small amphitheatrical cirque with the steep cliffs and jagged peaks surrounding it. The feature of especial significance is the broad glaciated rock terraces, especially prominent on the right.

Plate VI.

PLATE VII.

The 'Box' form of the canyon is again shown and the almost unbroken lateral moraine skirting the mountain on the left, less prominent on the right.

Plate VII.

PLATE VIII.

Another view of well defined lateral moraines.

Plate VIII.

PLATE IX.

A view showing the effect of ice on rounding a point.

Plate IX.

PLATE X.

View of a winding stream behind a terminal moraine.

Plate X.

Plate XII.

Plate 12.- A number of glacial lakes enclosed in till.

Plate 13.- A partial view of one of the largest cirques in the range (Uinta Canyon). On the left is seen a small lake occupying a depression between the lateral moraine and the mountain.

Plate XIV.

Approved
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